University of Fort Hare
Together in Excellence

# Characterization of livestock manures biochar and their effect on soil chemical properties and crop growth under glasshouse conditions

By


## Dzvene Admire Rukudzo


A dissertation submitted in fulfillment of the requirements for the degree of Master of Science in Agriculture (Crop Science)


**Promoter**

Prof C. Chiduza

**Co-promoters**

Prof P.N.S. Mnkeni
Prof S. Mamphweli

Department of Agronomy
University of Fort hare


October, 2017

## DECLARATION

I, Dzvene Admire Rukudzo **(Student Number: 201013385)**, hereby declare that this dissertation is the result of my own original work and that other scholars' works referred to here have been duly acknowledged. I also declare that this dissertation is original and has not been submitted elsewhere for a degree.

Signed at the Faculty of Science and Agriculture, Agronomy Department, University of Fort Hare, Alice campus, South Africa

______________________ ______________________

Dzvene Admire Rukudzo Date

Opinions expressed and conclusions derived are those of the author and are not necessarily to be attributed to University of Fort Hare.

## GENERAL ABSTRACT

Biochar is being promoted as an amendment to improve soil properties, crop productivity, and carbon sequestration. In Africa, biochar adoption is hindered by production systems which include technology and feedstocks availability. However, little research has been published on the influence of biochar incorporation on soil chemical properties and early crop establishment. The aim of this study was to characterize biochar from cattle, goat, sheep and poultry kraal manures and their effect on soil properties and crop growth. This was guided by the following specific objectives, (i) to explore the mixed-farming system of Raymond Mhlaba Municipality on availability and utilization of livestock kraal manures (ii) to characterize biochar samples produced from cattle, goat, sheep and poultry kraal manures (iii) to determine the nutrient release patterns of biochars amended in a degraded soil (iv) to determine the effectiveness of converting manure to biochar and cattle manure on maize early development and, (v) to determine the effects of biochar type and application rate on early maize development.

The farming system was surveyed to identify quantities of livestock manure, its availability and utilization for soil fertility amendment in cropping in the Raymond Mhlaba Municipality. The emerging results across all the villages revealed that, the mean livestock numbers were, 9.24±8.21 sheep, 9.37±8.15 goats, 7.95±7.66 cattle and 9.02±9.47 chickens. The findings revealed that 94 (82.4%) of the respondents had access to cropland allocations in the form of outfields and homegardens. However, only 55 (48.2%) of the respondents were currently cropping their fields. Maize was the most common crop grown followed by butternuts and potatoes. The application of manure by the respondents currently cropping their lands was only 40 (35.1%) and the quantities used ranged from 210-1450 kg $ha^{-1}$. The results further

showed that the estimated total manure production was 2.9 t year$^{-1}$, 0.82 t year$^{-1}$, 0.04 t year$^{-1}$, and 0.8 t year$^{-1}$ from cattle, goats, chicken, and sheeps respectively.

Drum retort method of slow pyrolysis at a temperature of 400°C was used to produce biochar from cattle, goat, sheep and poultry manure feedstocks. The biochar yields were 63%, 72%, 61% and 83% on a weight basis for the different feedstocks. The chemical properties of the biochar were significantly different from those of the manure from which they were made. Biochars that were high in Ca and K such as poultry manure biochar and sheep manure biochar indicated higher pH and electrical conductivity values. For instance, sheep manure biochar was (8.1 mS cm$^{-1}$) and poultry manure biochar was (9.2 mS cm$^{-1}$). The scanning electron microscopy (SEM) revealed that, the biochars had porous structures ranging from 1.23um to 5.23um in diameter which are important for water conductance and holding capacity.

The target soil carbon level to determine the effects of biochar soil incorporation was 2% and the soil had 0.7%. Therefore, it was treated with four livestock manure biochars at application rates of 0; 53.2 t ha$^{-1}$ (CMB); 48.1 t ha$^{-1}$ (GMB); 50.7 t ha$^{-1}$ (SMB); and 40.2 t ha$^{-1}$ (PMB) based on their carbon content to supplement the soil carbon difference. The effect on soil pH was such that SMB increased to 6.44, PMB (6.45), CMB (6.54), and GMB (6.53) relative to the control which did not show any changes. An increase was also observed on Olsen P concentrations (mg P kg$^{-1}$) which varied with biochar treatments: PMB (6.22), GMB (6.37), SMB (6.44) and CMB (6.44) and were significantly higher than the control. Ammonium-N ($NH_4^+$) concentrations (mg $NH_4^+$-N) were increased in biochar treatments but, no significant differences were obtained with sampling time. SMB released 7.95 mg kg$^{-1}$, CMB 7.50 mg kg$^{-1}$, PMB 7.46 mg kg$^{-1}$ and GMB 7.05 mg kg$^{-1}$, compared to the control 3.23 mg kg$^{-1}$.

Maize growth in soil sampled from farmers fields incultivation and abandoned treated with biochar without application of inorganic fertilizer did not differ with control (soil only) treatments. However, maize growth in soil treated with biochar and inorganic fertilizer was comparative to manure treatments. This resulted in a follow up study to elucidate the effects of biochar alone and was carried out with cattle, goat, sheep and poultry biochars at five application rates (0, 100, 200, 300, and 400 kg C $ha^{-1}$) applied to a sandy loam and a clayey loam soil of the Oakleaf and Tukulu soil forms respectively. Post-harvest soil pH, electrical conductivity and Olsen P showed improvements in biochar treatments relative to the control. Improvements in the chemical parameters and plant growth increased simultaneously with biochar application rate. Maize growth was not affected by biochar application at different rates.

*Keywords*: Biochar, cultivation history, crop production, farming system, soil fertility, livestock manures, soil organic carbon, nitrogen, phophorus

## PREFACE

This dissertation consists of eight chapters. The abstract gives a summary of the eight research chapters that follow. Chapter 1, is a general introduction giving background information of the study, justifying the reasons for conducting the study and outlines the specific objectives. In Chapter 2, a review of literature related to Characterization of livestock manures biochar and their effect on soil chemical properties and crop growth under glasshouse conditions is given. Chapters 3 to 7 are connected experiments which are presented in complete paper format with an introduction, specific objectives, hypotheses, materials and methods, results, discussion and conclusion. The final chapter focuses on discussion and conclusions which summarise the findings from the experiments conducted in this study and the recommendations. All the references cited are listed at the end of each chapter.

**ACKOWLEDGEMENTS**

Firstly, I would like to extend my deepest gratitude to the Almighty and Powerful, the Alpha and Omega, God for his providence, guidance throughout the whole study and an opportunity to broaden my horizons, his divine love and protection during this learning period and in my entire life. Without him I would not have started or finished this project. He is the author and finisher of my faith. It is by his grace that I wrote this dissertation and I am still here today. I give thanks to my parents for their support that has taken me this far, the principles of valuing education they cultivated in me at a tender age, I shall be forever grateful; I thank you Mum and Dad. My major supervisor Prof. Chiduza, and my co-supervisors, Prof P.N.S Mnkeni, and Prof S. Mamphweli for their continuous support, encouragements, and sharing their invaluable time and ideas they put into this work to shape it up to what it is. I am forever grateful for the support. This work was demanding but you were ever at my disposal.

My heartfelt thanks also go to my friends for your contribution to this work. I had friends that helped me to regain my strength by giving me positive ideas and encouragement until I finished this dissertation. These friends included Mr Patrick Nyambo, Mr Kudzayi Janhi, Mr Tendayi Kadango, Miss Sweetness Lukashe, Miss Sinazo Jacobs, Miss Khanya Njoloza, Mr. Isaac Gura, Dr Brian Muroyiwa and Mr Mthulisi Mpofu. Your presence and positive spirit helped me keep upright and indeed made me a better social being, regardless of the work pressure I endured. I would like to thank the Agronomy Department staff for providing me with all necessary facilities and their support, namely Mr Thanduxolo Ngqangweni, Miss Zikhona Goniwe, and Mr Trato. I am indebted to the University of Fort Hare Govan Mbeki Research and Development Centre (GMRDC) and the National Research Foundation (NRF) for their financial support.

## DEDICATION

*This study is my greatest achievement; I therefore dedicate it to the most special and closest people to my heart.*

For everything there is a purpose and l thank God for the experience I had throughout the two years of my work, I met wonderful people. I hope I touched those peoples' hearts as much as they touched mine.

I dedicate this work to my parents, and my brothers you are a blessing that I was given from above. To my parents I thank you for all the prayers, to my brothers I thank you for your support and this work is an inspiration to you that it can be done if you just dare to dream and dream big.

"*And without faith it is impossible to please him, for whoever would draw near to God must believe that he exists and that he rewards those who seek him."*

**(Hebrews 11 vs 6)**

## TABLE OF CONTENTS

DECLARATION .......... ii

GENERAL ABSTRACT .......... iii

PREFACE .......... vi

ACKOWLEDGEMENTS .......... vii

DEDICATION .......... viii

TABLE OF CONTENTS .......... ix

LIST OF TABLES .......... xvi

LIST OF FIGURES .......... xix

**1. GENERAL INTRODUCTION** .......... 1

1.1. Introduction .......... 1

1.2. Problem Statement .......... 5

1.3. Justification .......... 7

1.4. The scope and objectives of this study .......... 8

1.5. Study hypotheses .......... 9

**2. LITERATURE REVIEW** .......... 11

2.1. Introduction .......... 11

2.2. Characteristics of mixed farming systems .......... 12

2.2.1. Interaction of crop-livestock productivities .......... 13

2.2.2. Availability and utilization of livestock manure in Eastern Cape .......... 13

2.3. Agricultural land and degradation of soils in the Eastern Cape .......... 15

2.3.1. Role of soil organic carbon in soil fertility .......... 17

2.4. Conversion of biomass to biochar and its application .......... 18

2.4.1. Effects of feedstock characteristics ........................................................................ 19

2.4.2. Characteristics of biochar ........................................................................ 20

2.4.3. Effects of biochar on soil properties ........................................................................ 22

2.4.4. Biochars effect on crop growth ........................................................................ 25

2.5 Conclusion and recommendation ........................................................................ 28

**3. FARMING SYSTEM, AVAILABILITY AND UTILIZATION OF LIVESTOCK KRAAL MANURES IN RAYMOND MHLABA MUNICIPALITY, EASTERN CAPE PROVINCE, SOUTH AFRICA** ........................................................................ 29

Abstract ........................................................................ 29

3.1. Introduction ........................................................................ 31

3.2. Materials and methods ........................................................................ 34

3.2.1. Description and location of study site ........................................................................ 34

3.2.2. Selection of study sites ........................................................................ 34

3.2.3. Conduct of the survey ........................................................................ 36

3.2.4. Determining household livestock manure production ........................................................................ 37

3.2.5. Statistical analysis ........................................................................ 38

3.3. Results ........................................................................ 40

3.3.1. Household socio-economic demographics ........................................................................ 40

3.3.2. Smallholder farming system in the Raymond Mhlaba Municipality ........................................................................ 44

3.3.3. Estimating potential livestock manure production ........................................................................ 48

3.3.4. Livestock manure utilization for fertility management in cropping ........................................................................ 50

3.3.5. Factors influencing livestock manure utilization in cropping ........................................................................ 52

3.4. Discussion ........................................................................................................55

3.4.1. Household socio-economic demographics ...........................................................55

3.4.2. Characteristics of smallholder farming system ....................................................57

3.4.3. Potential livestock manure production quantities..................................................59

3.4.4. Livestock manure use by smallholder farmers ......................................................60

3.4.5. Household factors influencing manure use by smallholder farmers ......................61

3.5. Conclusions and recommendations...............................................................................63

**4. CHARACTERISTICS OF BIOCHAR PRODUCED FROM SLOW PYROLYSIS OF LIVESTOCK MANURES FOR AGRONOMIC APPLICATION** ..................................64

Abstract ..........................................................................................................................64

4.1. Introduction ...................................................................................................................66

4.2. Materials and methods ...................................................................................................69

4.2.1. Manure resources and preparation..........................................................................69

4.2.2. Slow pyrolysis tests ................................................................................................70

4.2.3. Manure and biochar characterization .....................................................................71

4.2.4. Data analysis............................................................................................................72

4.3. Results ............................................................................................................................73

4.3.1. Biochar yield and proximate analysis......................................................................73

4.3.2. Biochars pH and electrical conductivity...................................................................76

4.3.3. Nutrient characteristics ............................................................................................77

4.3.4. Physical characteristics.............................................................................................79

4.4. Discussions.....84

4.4.1. Biochars yield and proximate analysis.....84

4.4.2. Biochars pH and electrical conductivity.....85

4.4.3. Biochars nutrient characteristics.....86

4.4.4. Biochars physical and structural characteristics.....87

4.5. Conclusion and recommendations.....88

**5. CARBON AND AVAILABLE NITROGEN AND PHOSPHORUS RELEASE IN AN OAKLEAF SOIL AMENDED WITH DIFFERENT LIVESTOCK MANURE BIOCHARS**.....90

Abstract.....90

5.1. Introduction.....92

5.2. Materials and methods.....96

5.2.1. Soil collection, analysis and biochar treatments.....96

5.2.2. Incubation experiment and sample analysis.....97

5.2.3. Statistical analysis.....99

5.3. Results.....99

5.3.1. Dynamic changes of soil carbon (C) from livestock manure biochars amended soil under incubation.....99

5.3.2. Changes in pH and electrical conductivity from livestock manure biochars amended soil under incubation.....103

5.3.3. Inorganic nitrogen ($NH_4^+$-N, and $NO_3^-$-N) and total nitrogen (TN) release from livestock manure biochars amended in an Oakleaf soil under incubation.....104

5.3.4. Bicarbonate-extractable phosphorus (Olsen-P) release dynamics from livestock manure biochars amended soil under incubation ........................................................ 106

5.3.5. Soil water holding capacity dynamics associated with livestock manure biochars amendments to an Oakleaf soil under incubation ........................................................ 111

5.4. Discussion ........................................................ 112

5.4.1. Biochar effects on soil pH and electrical conductivity dynamics ........................ 112

5.4.2. Biochar effects on carbon dynamics ........................................................ 114

5.4.3. Biochar effects on nitrogen dynamics ........................................................ 115

5.4.4. Biochar effects on bicarbonate-extractable phosphorus (Olsen-P) dynamics ...... 115

5.4.5. Biochar effects on water holding capacity dynamics ........................................ 115

5.5. Conclusion and recommendations ........................................................ 116

**6. COMPARATIVE EFFECT OF AMENDMENTS ON DEGRADED HUTTON SOIL OF DIFFERING CULTIVATION HISTORY WITH MANURE AND ITS BIOCHAR ON MAIZE SEEDLINGS GROWTH** ........................................................ 117

Abstract ........................................................ 117

6.1. Introduction ........................................................ 119

6.2. Materials and methods ........................................................ 123

6.2.1. Soil sampling, and preparation ........................................................ 123

6.2.2. Soil analysis ........................................................ 124

6.2.2. Treatments and experimental design ........................................................ 125

6.2.3. Non-experimental variables ........................................................ 125

6.2.4. Data collection ........................................................ 127

6.2.5. Statistical analysis....................127
6.3. Results....................128
6.3.1. Differences in selected soil properties of soils sampled from > 5 years in cultivation and > 5 years abandonment farmers' fields....................128
6.3.2. Effects of cultivation history and fertility strategy on maize seedling growth and total biomass yield at harvest....................129
6.4. Discussions....................135
6.4.1. Influence of cultivation history on selected soil properties....................135
6.4.2. Effects of cultivation history and soil fertility management strategy on maize seedling growth....................135
6.5. Conclusion and recommendations....................138
**7. EFFECT OF SOIL TYPE, MANURE BIOCHAR TYPE AND APPLICATION RATE ON GROWTH OF MAIZE SEEDLINGS AND SOIL CHEMICAL PROPERTIES**....................139
Abstract....................139
7.1. Introduction....................141
7.2 Materials and methods....................143
7.2.1. Experimental factors, treatments and design....................143
7.2.2. Non experimental variables....................145
7.2.3. Analysis of post-harvest chemical properties of soil-biochar mixtures....................146
7.2.4. Plant growth data collection....................146
7.2.5. Statistical analysis....................147
7.3. Results....................147

7.3.1. Influence of biochar type, and biochar rate on post-harvest chemical properties of an Oakleaf and a Tukulu soil ............ 147

7.3.2. Influence of soil type, biochar type and biochar rate on maize seedling germination, growth and total biomass yield at harvest ............ 151

7.4. Discussions ............ 160

7.4.1. Effects of biochar type and rate on post-harvest soil chemical properties ............ 160

7.4.2. Effects of soil type, biochar type and application rate on maize seedling growth161

7.5 Conclusion and recommendations ............ 163

**8. GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH** ............ 164

8.1. Motivation and objective of the study ............ 164

8.2. General discussion of findings ............ 165

8.3. Relevance and limitations of findings ............ 170

8.5. Conclusions ............ 171

8.6. Recommendations ............ 173

**REFERENCES** ............ 175

**APPENDICES** ............ 206

## LIST OF TABLES

**Table 2.1**: Overview of pyrolysis methods with regards to biochar yield ............................. 18

**Table 2.2**: Effects of livestock manure biochars applied as a soil amendment....................... 27

**Table 3.1**: GPS coordinates and population in five villages selected for the survey on farming systems and availability of manure........................................................................... 36

**Table 3.2**: Assumptions made in estimating the potential manure production in the study ... 38

**Table 3.3**: Proportions of female and male-headed households interviewed in five villages selected for survey in Raymond Mhlaba Municipality.......................................................... 40

**Table 3.4**: Mean household size and number of members per age group distribution in households interviewed in Raymond Mhlaba Municipality ................................................... 41

**Table 3.5**: Mean educational status of household heads interviewed in Raymond Mhlaba Municipality........................................................................................................................ 42

**Table 3.6**: Mean score (rank) of household sources of income in selected villages of Raymond Mhlaba Municipality............................................................................................. 43

**Table 3.7**: Mean distributions of farm sizes as homegardens and outfields across the study locations (n =94) ................................................................................................................. 44

**Table 3.8**: Potential manure production in kg DM/year from cattle, goat, chicken and sheep numbers for the study sites and households using manure in cropping.................................. 49

**Table 3.9**: Potential manure production in kg DM/year per household of farmers applying manure as fertility amendments in cropping (n = 40)............................................................. 49

**Table 3.10**: The reason given by household heads for not using manure in cropping (n = 15) ........................................................................................................................................... 50

**Table 3.11**: Characteristics of household manure utilization by gender in Raymond Mhlaba Municipality (n = 40) ........ 51
**Table 3.12**: Mean manure application quantities (kg) by gender in Raymond Mhlaba Municipality (n = 40) ........ 52
**Table 3.13**: Summary statistics for the binary logistic model ........ 53
**Table 3.14**: Parameter estimates of maximum likelihood for manure utilization according to binary logistic regression (n = 55) ........ 53
**Table 3.15**: One-way ANOVA for factors influencing quantities of manure applied by the households (n = 40) ........ 54

**Table 4.1**: Comparison of livestock manures and their biochars with respect to pH, electrical conductivity, and C/N ratio ........ 76
**Table 4.2**: Comparison of livestock manures and their biochars with respect to total C, total N, total K, total Ca and total Mg ........ 78
**Table 4.3**: Comparison of selected physical characteristics of biochars produced from livestock manures ........ 80
**Table 4.4**: Comparison of livestock manures and their biochars with respect to Na, Zn, Cu, Mn, Fe and Al ........ 81

**Table 5.1**: Physical and chemical characteristics of the soil used in this study ........ 96
**Table 5.2**: Summary analysis of variance (ANOVA) results for livestock manure biochar effects, sampling time, and interaction for dynamics in selected physical and chemical soil properties analyzed following destructive sampling over 42 days of incubation ........ 101
**Table 5.3**: Effects of biochar soil amendments on changes in soil NO3-N during incubation of cattle, goat, sheep, and poultry livestock manure biochars ........ 109

**Table 6.1**: Selected properties of a Hutton soil sampled from > 5 years in cultivation and > 5 years abandonment farmers' fields ........................................................................ 124

**Table 6.2**: Selected properties of a Hutton soil sampled from > 5 years in cultivation and > 5 years abandonment farmers' fields ........................................................................ 128

**Table 6.3**: ANOVA for maize parameters grown in > 5 years in cultivation and > 5 years abandonment Hutton soil, and the effects of six fertility amendment strategies, and interaction ........................................................................ 130

Table 7.1: Selected soil properties of soil used for the biochar amendment glasshouse study ........................................................................ 144

**Table 7.2**: Biochar treatments and actual rates used for each carbon desired application rate based on biochar carbon contents ........................................................................ 145

**Table 7.3**: Actual amount of biochar used in a bag for each carbon desired application rate ........................................................................ 145

**Table 7.4**: ANOVA for data on post-harvest soil pH, electrical conductivity, and Olsen P. 147

**Table 7.5**: ANOVA results showing maize seedling germination percentage with application of four biochar types, at five rates and, and their interactions ........................................ 152

**Table 7.6**: ANOVA results showing maize height and leaf number with application four biochar types, at five rates and, and their interactions ........................................ 153

## LIST OF FIGURES

**Figure 3. 1:** Map of Eastern Cape Province showing the location of the district and selected villages in the Raymond Mhlaba Municipality where interviews were administered to crop-livestock farmers. ....................................................................................................35

**Figure 3.2:** Mean sizes of homegardens and outfields size (ha) for the 94 households with farmland distributed by gender .......................................................................................45

**Figure 3.3:** Proportion responses of crops grown (homegarden and outfield) by gender of the 55 households cropping ......................................................................................46

**Figure 3.4:** Responses of crops grown (homegarden and outfield) by village (n= 55) ..........47

**Figure 3.5:** Household livestock numbers (sheep, goat, cattle and chicken) distribution in the studied villages of Raymond Mhlaba Municipality (n =114).................................................48

**Figure 3.6:** Mean livestock manure quantities applied at farmers' households with land size for outfield farm sizes .......................................................................................55

**Figure 4.1**: Representation of the slow pyrolysis retort .........................................................71

**Figure 4.2**: Biochar yields prepared from livestock manures using slow pyrolysis at 400$^o$C 74

**Figure 4.3**: Comparisons of (a) Moisture, (b) volatile, (c) ash, (d) fixed carbon of livestock manures biochar produced with slow pyrolysis at 400$^o$C.......................................................75

**Figure 4.4**: Scanning electron microscopy (SEM) images for the biochars produced from (a) Cattle manure, (b) Poultry manure, (c) Goat manure, and (d) Sheep manure .........................82

**Figure 4.5**: Scanning electron microscopy (SEM) images with diameters of micropores for the biochars produced from (a) Cattle manure, (b) Poultry manure, (c) Goat manure, and (d) Sheep manure.........................................................................................................83

**Figure 5.1**: Changes in (a) TC (%) and (b) SOC (%) during 6 weeks of soil incubation treated at 2% C equivalent to 53.2, 48.4, 50.7, and 40.2 Mg $ha^{-1}$ for cattle, goat, sheep and poultry manure biochar, respectively. ........ 102

**Figure 5.2**: Changes in (a) pH and (b) electrical conductivity during 6 weeks of soil incubation treated at 2% C equivalent to 53.2, 48.4, 50.7, and 40.2 Mg $ha^{-1}$ for cattle, goat, sheep and poultry manure biochar, respectively. ........ 105

**Figure 5.3**: Changes in (a) NH4+-N (mg/kg), and (b) $NO_3$--N (mg $kg^{-1}$) during 6 weeks of soil incubation treated at 2% C equivalent to 53.2, 48.4, 50.7, and 40.2 Mg $ha^{-1}$ for cattle, goat, sheep and poultry manure biochar, respectively. ........ 107

**Figure 5.4**: Effects of biochars on (a) total nitrogen (%), (b) $NO_3$--N (mg $kg^{-1}$) during 6 weeks of soil incubation treated at 2% C equivalent to 53.2, 48.4, 50.7, and 40.2 Mg $ha^{-1}$ for cattle, goat, sheep and poultry manure biochar, respectively. ........ 108

**Figure 5.5**: Changes in Olsen P (mg $kg^{-1}$) during 6 weeks of soil incubation treated at 2% C equivalent to 53.2, 48.4, 50.7, and 40.2 Mg $ha^{-1}$ for cattle, goat, sheep and poultry manure biochar, respectively. ........ 110

**Figure 5.6**: Changes in WHC (%) during 6 weeks of soil incubation treated at 2% C equivalent to 53.2, 48.4, 50.7, and 40.2 Mg $ha^{-1}$ for cattle, goat, sheep and poultry manure biochar, respectively. ........ 111

**Figure 6.1**: Interactive (C × F) effects on mean height at 42 DAP. Error bars denotes standard error of the mean, and different letters significant differences ($P<0.05$). ........ 131

**Figure 6.2**: Interactive (C × F) effects on mean leaf number at 42 DAP. Error bars denotes standard error of the mean, and different letters significant differences ($P<0.05$). ........ 132

**Figure 6.3**: Interactive (C × F) effects on mean leaf area at 42 days after planting. Error bars denotes standard error of the mean, and different letters significant differences ($p<0.05$). ........ 133

**Figure 6.4**: Mean dry biomass yields at 42 days after planting (harvest). Means with different letters are significantly different at p<0.05. Error bars represent standard error. ..................134

**Figure 7.1**: Interactive (Br × St) effects on post-harvest soil pH. Error bars denotes standard error of the mean, and different letters significant differences (p<0.05) ..............................149

**Figure 7.2**: Interactive (Br × St) effects on post-harvest soil electrical conductivity (mS $cm^{-1}$). Error bars denotes standard error of the mean, and different letters significant differences (p<0.05)..........................................................................................................................150

**Figure 7.3**: Interactive (Bt × St) effects on post-harvest soil electrical conductivity (mS $cm^{-1}$). Error bars denotes standard error of the mean, and different letters significant differences (p<0.05)..........................................................................................................................151

**Figure 7.4**: Interactive (Bt × St) effects on maize height (cm) determined at 14 days after planting. Error bars denotes standard error of the mean, and different letters significant differences (p<0.05). ..........................................................................................154

**Figure 7.5**: Interactive (Br × St) effects on maize height (cm) determined at 14 days after planting. Error bars denotes standard error of the mean, and different letters significant differences (p<0.05). ..........................................................................................155

**Figure 7.6**: Interactive (Bt × Br) effects on maize height (cm) determined at 28 days after planting. Error bars denotes standard error of the mean, and different letters denote significant differences (p<0.05). ..........................................................................................156

**Figure 7.7**: Interactive (Bt × Br × St) effects on maize height (cm) determined at harvest (42 days after planting). Error bars denotes standard error of the mean, and different letters significant differences (p<0.05). ..........................................................................157

**Figure 7.8**: Interactive (Bt × Br × St) effects on maize leaf number determined at 28 days after planting. Error bars denotes standard error of the mean (p<0.05). .......................................158

**Figure 7.9**: Comparison of maize total dry biomass with biochar application rate .............159

# 1. GENERAL INTRODUCTION

## 1.1. Introduction

The Eastern Cape Province (EC) has severely degraded soils (Hoffman *et al*., 1999; Mkile, 2001). These soils are characterized by low soil organic matter (SOM) content, acidic conditions, low nutrient retention resulting in low crop yields (Mandiringana *et al*., 2005; Van Averbeke *et al*., 2008). Practices such as continuous maize (*Zea Mays* L.) monoculture and conventional tillage, which are common in the smallholder sector are responsible for the accelerated SOM loss as well as, a decline in soil fertility and crop yields in the Province (Mandiringana *et al*., 2005). For example, rain-fed average maize grain yields, were observed to have declined from around 700 kg $ha^{-1}$ to 200 kg $ha^{-1}$ over a 50-year period from 1930 to 1980 (Bembridge, 1984). Mkile (2001) also noted a similar decline and cited figures of yield reduction from 636 kg $ha^{-1}$ to 189 kg $ha^{-1}$ over an 80-year period that stretched between 1918 and 1998. Literature suggests that there has been little improvement in maize yields (Murungu *et al*., 2010). Hence, dry land maize production in the smallholder sector is not sustainable under the present management conditions.

Soil organic carbon (SOC) is an important soil quality parameter and is a dominant fraction of SOM. It contributes to the soil's nutrient holding capacity, nutrient turnover and stability, water holding capacity and soil fertility status (van Wambeke, 1992; Brady and Weil, 2012). Conservation agriculture is being promoted by the Eastern Cape Department of Agriculture (ECDA) as one strategy for improving the dry land cropping systems in the province. The latter strategy helps to address soil degradation through the addition of organic matter in the form of retained crop residues (Murungu, 2012) and contributes to improved SOM through enhanced soil carbon (C) sequestration (Solaiman and Anawar, 2015; Lone *et al*., 2015). Although fresh organic amendments increase soil carbon, supply nutrient bases, and condition the soilhowever, they mineralize quickly in the soil and these benefits only last for a few growing seasons (Hall and Bell, 2015; Abbasi and Anwar, 2015). Therefore, other amendments such as biochar are being investigated as alternatives to the application of fresh organic amendments.

Biochar is a black carbon solid residue obtained from heating biomass under oxygen-limited conditions (Calderon *et al*., 2015). It has the potential of improving the productivity of soils through sequestering recalcitrant carbon in the soil, soil conditioning and enhancing nutrient recycling (Uzoma *et al*., 2011). Biochar, unlike fresh organic amendments, mineralizes slowly in soil (Calderon *et al*., 2015) leaving a stable carbon fraction with age greater than that of the oldest SOC fractions (Zhao *et al*., 2015). As a result, it could be more effective in increasing soil C well beyond what is achieved through CA practices (Laird, 2008; Singh *et al*., 2015). Adopting the application of biochar could go a long way in improving soil properties and crop yields in rain fed production in the central region of the EC.

In addition to its ability to increase carbon sequestration, biochar has high surface area per unit mass and high charge density thus, giving it a higher capacity to sorb cations per unit mass than SOM (Liang *et al*., 2006). Biochar conditions the soil while, modifying soil characteristics leads to positive changes in soil physical and chemical properties (Novak *et al*., 2009; Chan *et al*., 2008; Glaser *et al*., 2002). This property is also important in improving nutrient release and water-holding capacity (WHC) in poor sandy soils (Sika, 2012).

The characteristics of biochar could be an entry point in promoting its utilization in the EC if it proves to be better than its feedstock material in modifying soil chemical properties and improving early crop growth. A recent study by Stella Mary *et al*. (2016) concluded that slow pyrolysis (600$^o$C) of three feedstock materials (cauliflower leaf, orange peel, and pea pod) resulted in biochars of different physicochemical properties. This implies that, biochar properties are not influenced by method of production alone. Calderon *et al*. (2015) in a comprehensive study evaluated the significance of converting maize residue biomass to biochar with two pyrolysis temperatures at 300$^o$C and 500$^o$C. The results indicated that, total N and C of the feedstock increased with the pyrolysis temperature.

According to Martinsen *et al*. (2014) and Calderón *et al*. (2015), biochar derived from plant feedstocks has high percentage carbon contents ranging approximately between 50-70% as contrasted to the lower carbon contents in manure-based biochars which range between 20-40% (Inal *et al*., 2015; Tsai *et al*., 2012). Unfortunately, plant-based biochars are known to have low mineral ash content with little to no nutrient value (Stella Mary *et al*., 2016; Calderon *et al*., 2015) when compared to manure based biochars which, are reported to have higher ash content resulting in significant nutrient (Ca, Mg, N, P, K) values (Inal *et al*., 2015; Uzoma *et al*., 2011). Thus, adoption of manure biochars could go a long way in improving soil fertility and crop growth. However, it is important to note that chemical and physical differences in manure-based biochars will not only depend on the animal type, but also on its diet, state of animal waste and whether it is manure or litter (Chan *et al*., 2008; Parvage *et al*., 2015). Hence, there is need to determine manure-based biochar chemical characteristics in comparison to its manure feedstock material.

The extant literature on the utilization of livestock manures as soil fertility amendment in the EC by earlier researchers showed yield improvements (Yoganathan *et al*., 1998; Mkile, 2001). Manure use in mixed farming is a critical resource for organic matter and soil fertility improvements (Yoganathan *et al*., 1998). In mixed-farming practices where livestock production is of importance, the use of crop residues as livestock feed is traditional (Yoganathan *et al*., 1998; Mkile, 2001). Removal of organic matter from crop-fields through livestock crop residues grazing contributes to the destruction of poor inherent soil fertility (Mandiringana *et al*., 2005; Van Averbeke *et al*., 2008). Thus, utilization of livestock manure for soil fertility management as a complementarity is pivotal. Previous studies have shown that amendments of biochar to the soil can improve its quality which results in improved crop growth and grain yields (Calderon *et al*., 2015; Uzoma *et al*., 2011).

In addition, application of biochar could minimize the problem of nutrient loss by leaching because it has a higher capacity to adsorb cations and anions from soil solution (Sarkhot *et al*., 2012). For instance, biochar produced from wood biomass can have cation exchange capacities (CEC) of up to 490-cmol $kg^{-1}$ (Radlein *et al*., 1996) and an anion exchange capacity (AEC) of 88.2 cmol $kg^{-1}$ (Fujita *et al*., 1991). Furthermore, Brady and Weil (2012) also reported CEC values for soil components which included $< 5$ cmol $kg^{-1}$ for sand, $< 10$ cmol $kg^{-1}$ for oxides, $< 15$ cmol $kg^{-1}$ for kaolinite, $< 150$ cmol $kg^{-1}$ for smectite, and $< 250$ cmol $kg^{-1}$ for organic matter (OM) in soil. The emermging results from all these studies suggest that biochar application in sandy soil can improve its CEC and fertility. In other words, amending soil with biochar will not only increase the SOC but, will also increase the potential of soil to exchange nutrient cations within the soil solution and consequently improve soil fertility and increase crop growth.

The effects of biochar on crop growth can be positive or negative depending on the biochar feedstock material and application rate (Zhu *et al*., 2014). Cornelissen *et al.* (2013) observed an increase in maize grain yield in biochar treatments when compared to non-biochar treatments in a field experiment. Whereas, pot experiments showed increased maize growth at early stages which showed positive correlation to the final harvested yield by 2.2 $tha^{-1}$ over the control (Kimetu *et al*., 2008; van Zwieten *et al*., 2009). On the other hand, sandy soil amended with cattle manure biochar at 15 $tha^{-1}$ improved maize plant height and the number of leaves by 66% and 60% respectively, as compared to the control (no-biochar) treatments in an 85-day growth study (Uzoma *et al*., 2011). However, a study conducted by Jeffery *et al*. (2016) highlighted that, meta-analysis studies have cautioned that biochar application can suppress plant growth or reduce nutrient availability.

### 1.2. Problem Statement

Application of livestock manures to soil supplies organic matter (OM) which buffers soil pH, improves soil structure and hydraulic properties and releases plant nutrients for plant uptake during mineralization. However, soil benefits of livestock manure amendments are short lived and last for a few seasons due to rapid soil mineralization (Yoganathan *et al*., 1998; Mnkeni and Mkile, 2001). Hence, attention has been given to alternative strategies. Transformation of biomass through pyrolysis has been advocated for as a potential strategy for the sequestration of soil carbon, and soil fertility improvement through enhanced soil nutrient supply. According to Lehmann *et al*. (2009), if the produced charcoal is used as a soil amendment, it is termed "biochar" owing to its remedial potential in improving soil fertility, acidity and structure. This suggest that, the realized benefits supplied with livestock manure are highly improved with conversion to biochar (Chan *et al*., 2008; Touray *et al*., 2014).

According to Revell *et al*. (2012) if the pyrolysis of livestock manure to biochar improves its carbon stability and concentrates nutrients then, livestock manure biochar could be promoted as a potential feedstock in South African mixed agriculture. Lehmann *et al*. (2009) found that on average, a ton of dry feedstock can produce about 400kg of biochar. Currently, there is dearth of recent literature on household livestock manure availability and its utilization in the EC Province. Amending biochar to soil can improve SOC. Additionally, since the effects of SOC on soil fertility are known this infers that, biochar could contribute significantly in soil fertility restoration in South African degraded areas specifically in the EC. An earlier study by Mandiringana *et al*. (2005) indicates that SOC values of 2% is the upper threshold below which most soils are infertile. However, these values are based on SOC quantity and say nothing on quality. As a potential solution to soil fertility problem, interest in research has shifted in determining the synergistic effects of livestock manure biochar type and soil type on the improvement of soil chemical properties and early crop growth. For instance, in Western Cape sandy soils, pine bark biochar application resulted in increased soil nutrient availability for crop growth (Sika, 2012). Rajkovich *et al*. (2012) cautioned that biochar's negative or positive effects on crop performance are highly dependent on the biomass feedstock type and pyrolysis processing conditions. Moreover, Utomo *et al*. (2012) implicated that biochar's priming effect on SOM results in temporary nitrogen immobilizations, which can affect crop growth performance at early stages. This is despite the fact that N immobilization is useful because of its capability to reduce N leaching and enhance N retention in agricultural soils (Zheng *et al*., 2013).

**1.3. Justification**

The extant literature indicates that the utilization of livestock manure is an ancient agricultural practice used to improve soil and crop productivity (Mkile *et al*., 2001; Yoganathan and van Averberke, 1996; Parvage *et al*., 2015). Kraal manure is the dominant form of livestock manure available in the EC Province mixed farming practices, and is used by at least 54% of the smallholder farmers in the Transkei region as fertility amendments in cropping (Yoganathan and Van Averbeke, 1996). A follow up study by Mkile (2001) to quantify manure availability in the Transkei showed that kraal manure quantities at farmer's homesteads ranged from 9.79 to 44.29 tonnes. However, an earlier study by Yoganathan *et al*. (1998) concluded that a minority of farming households were not utilizing livestock manures as a fertilizer due to numerous reasons.

Therefore, linked with the foregoing assertions, the need to update known information by exploring manure resources and quantities in Raymond Mhlaba municipality so as to promote alternative strategies is paramount. Transformation of livestock manures so as to improve their soil stability through converting them into biochar has been advocated for as a strategy to sustainably sequester soil carbon (Arthur *et al*., 2015; Calderon *et al*., 2015). Characterization of feedstocks and their biochar is necessary in evaluating the agronomic potential for soil application. Previous studies from other countries such as America, Japan and Australia, have shown that charred cattle manure significantly improved soil properties and increased maize grain yield (Jin *et al*., 2015). Whereas, wheat plant biomass also increased following charred paper mill waste addition (Van Zwieten *et al*., 2010). Unfortunately, though biocharring of biomass into a char (biochar) form is being promoted, there is an indication that research studies on biochar produced from livestock manures in South Africa are scanty.

### 1.4. The scope and objectives of this study

The research objectives of this study were guided by the questions (i) "Can any type of livestock manure be used in biochar production?" and, (ii) "Can any livestock manure biochar type ameriolate SOC and fertility in degraded soils of the EC and improve maize growth?" The main objective of the study was to evaluate the use of locally produced livestock manure biochars in improving the fertility of EC soils and the early growth (seedling) of maize (*Zea mays* L.).

The specific objectives of the study were to:

(a) Describe farming systems in the Raymond Mhlaba Municipality with regards to the availability and utilization of livestock kraal manures in cropping.

(b) Characterize the chemical and physical properties of biochar produced from sheep, goat, poultry and cattle manures.

(c) Determine the nutrient release patterns of biochar produced from sheep, goat, poultry and cattle manures amendment in an Oakleaf soil.

(d) Evaluate maize growth response to varying amounts of sheep, goat, poultry and cattle manure biochar's under glasshouse conditions.

(e) Determine the residual effect of biochar's produced from sheep, goat, poultry and cattle manure on the soil nutrient status after maize harvest.

(f) Evaluate maize growth response to optimum cattle manure application rate and its optimum manure rate converted to biochar application to soils of different cultivation histories.

## 1.5. Study hypotheses

The hypothesis for this study was:

(a) The availability and utilization of livestock kraal manure in crop farming systems of Raymond Mhlaba Municipality is not different.

(b) Chemical and physical properties of biochar produced from sheep, goat, poultry and cattle manures are not different.

(c) Nutrient release patterns of biochar's produced from sheep, goat, poultry and cattle manures are the same.

(d) The growth response of maize to varying amounts of sheep, goat, poultry and cattle manure biochar's is the same.

(e) There is similar residual effect of biochar's produced from sheep, goat, poultry and cattle manure on the soil nutrient status.

(f) Growth responses of maize test crop to optimum cattle, goat and sheep manure application rate and optimum manure rate converted to biochar are not different.

# 2. LITERATURE REVIEW

## 2.1. Introduction

Mixed farming systems contribute to the sustainability of livelihoods in rural populations where maize staple cropping and small ruminant rearing agricultural activities are combined (van Averberke *et al*., 2008). The combination and interdependence of crop production and livestock husbandry are the main characteristics in smallholder farming systems. Interactions of crop and livestock components is a two-way relationship where crop residues are fed to livestock, which provide traction and generate manure. Manure inclusion in soil fertilization practices is an important option for organic fertilizer, a source which is readily available at each farmers' household (Thornton and Herrero, 2001). However, the weakness in smallholder farming system is associated with poor fertilizer use and manure underutilization. This results in continuous nutrient mining by grain harvest which is worsened through livestock residue feeding and leads to degradation of the soil. Consequently, this resulting in low crop productivity.

According to Muhereza *et al.* (2014), the factors that make smallholder farmers not to fully utilize manures are high labour requirements and handling concerns. Bio-charring of manures improves the easiness in handling manure feedstock materials especially if its utilization is limited by factors such as poor sanitation and risk of harmful pathogens. In addition, biocharring of organic matter and soil application has been advocated for as a novel carbon sequestration approach and a climate-smart mitigation strategy over fresh organic amendments (Calderon *et al*., 2015; Jaafar *et al*., 2015). Furthermore, some of the benefits of bio-charring include improved soil fertility (Calderon *et al*., 2015), crop productivity and slow mineralization (Mukherjee and Lal, 2013).

Within the African context, biochar evaluation has focused largely on waste materials of plant origin as feedstock (Sika and Hardie, 2012). This is an indiction that, there is need to encourage agronomic utilization of biochar produced from manure or wastes of animal origin. These sentiments are supported by Uzoma *et al*. (2011), Chan *et al*. (2008) and Inal *et al*. (2015) who posit that, biochar produced from cattle and poultry litter manure have shown to improve soil properties and crop productivity.

## 2.2. Characteristics of mixed farming systems

Crop and livestock production are the components of a mixed farming system in sub-Saharan Africa (SSA) and in other parts of the world (Descheemaeker *et al*., 2010). In this system, there is a strong interrelationship in resource use, where outputs from one component are supplied to the other component (Thornton and Herrero, 2001). Food crops commonly grown for subsistence household utilization include maize (*Zea mays* L.), beans (*Phaseolous vulgaris*), sorghum (*Sorghum bicolor*), cabbage (*Brassica oleracea var. capitata*), and spinach (*Spinacia oleracea*) (Manyevere *et al*., 2014). Whereas, the livestock production is characterized by rearing of sheep, goat, cattle and poultry. It is estimated that about 600 million of communal farmers' livelihoods are supported by livestock production (Thornton, 2010). Therefore, improvement in agronomic production is made possible by manure utilization while, the remaining the crop residues after crop harvest are utilized by livestock production as a feed (Yoganathan *et al*., 1998). Manure inputs are fed into the system through livestock rangeland grazing (Thornton and Herrero, 2001). Nutrient cycling is achieved through manure droppings in rangeland during the day, and manure which accumulates in pens (kraals) during the night is applied in cultivated fields (Mkile, 2001).

### 2.2.1. Interaction of crop-livestock productivities

According to Descheemaeker *et al*. (2010), livestock plays an important role in supporting resource-poor farm households by offering a range of products and services. The major products obtained from livestock include: draught power, meat, milk, eggs and manure. Most importantly, livestock services and products serve as a financial reserve and act as an alternative source of income in events of uncertainties such as crop failure (Ali *et al*., 2011). Thus, from an agronomic perspective, interaction is not only through the utilization of livestock manures in crop cultivation but, also through livestock service production.

### 2.2.2. Availability and utilization of livestock manure in Eastern Cape

In the EC, studies encouraging manure utilization have been undertaken (Yoganathan *et al*., 1998). For example, during that time, livestock numbers ammounted to 3.28 million sheep, 2.23 million goats and 1.73 million cattle (Yoganathan *et al*., 1998). The estimated total of dry manure production in Transkei amounted to about 1.6 metric tonnes (MT) (Mnkeni and Mkile, unpublished). The survey also estimated that dry manure production per year at household level amounted to 15 tonnes of cattle whereas, for sheep and goats the dry manure amounted to 19 tonnes (Mnkeni and Mkile, unpublished). Thus, large amounts of livestock manures were reported to accumulate in household kraals (Mnkeni and Mkile, 2006). However, a survey revealed that out of 80 crop-livestock farmers that were interviewed, only 43 (53.7%) were utilising manure hence, the quantities used by these farmers varied (Yoganathan *et al*., 1998).

A survey on the nutrient concentrations of kraal manures from six villages in the central EC showed great variability. The nutrient concentrations were ranging from 21-82% (organic matter content), 1.98-5.01% (nitrogen), 0.45-2.19% (phosphorus) and 0.6-21.38% (potassium) (Yoganathan *et al*., 1998). Another study conducted by Mkile *et al*. (2001) in the Transkei for manure of goat, sheep and cattle kraal showed variations in nutrient concentrations, where N, P, and K ranged from, 9.9-16.7 $gkg^{-1}$, 2.0-3.6 $gkg^{-1}$, and 17.2-23.7 $gkg^{-1}$, respectively. Thus, the results indicated that, although manure had nutrient values, its effect upon soil application may not produce similar results and will be determined by crop needs.

Soil nutrient mining associated with crop harvest, and subsequent livestock grazing of crop residue aggravates the inherent low soil fertility problems (Mnkeni and Mkile, unpublished). Utilization of kraal manure with or without the combination of inorganic fertilizers differs amongst the farmers (Mkile *et al*., 2001). The common crops grown in the EC are maize, cabbages and field beans (Mkile *et al*., 2001; van Averberke *et al*., 2004; Manyevere *et al*., 2014). These crops are grown in outfields with sizes ranging from 1-3 ha (Manyevere *et al*., 2014; Mkile *et al*., 2001). These results imply that, only 300 to 1820 kg $ha^{-1}$ (Yoganathan *et al*., 1998) and 123 to 2650 kg $ha^{-1}$ (Mkile, 2001) of manure application is applied once a year mean. Therefore, most of the manure remains unutilized throughout the year.

**2.3. Agricultural land and degradation of soils in the Eastern Cape**

According to Nciizah and Wakindiki (2013) and Mandiringana *et al*. (2005), soils in many parts of the EC Province are sandy-loam dominated by quartz primary minerals. Low SOC (Mandiringana *et al*., 2005), low soil fertility and acidic conditions limit sustainable crop production especially under smallholder farming conditions. Hence, agricultural potential for crop cultivation highly depends on sound fertility management and irrigation (Fanadzo, 2012). Dry-land cultivation through subsistence maize farming dominates crops grown in the EC Province (Manyevere *et al*., 2014).

Meanwhile, the nature of parent materials from which the soil is formed influences its behavior (Brady and Weil, 2012). Parent materials originate from one or more of the following; underlying rock (granite, dolerite), deposits (water – Alluvium; wind – Aeolian; gravity - Colluvium), or volcanic deposits (Brady and Weil, 2012). Accordingly, Mandiringana *et al*. (2005) mention in their study that quartz, mica and kaolinite mineral dominate clay fraction found in the EC soils. This has resulted in these large quantities of quartz contributing to poor soil chemical and physical properties (Nciizah and Wakindiki, 2013). Whereas, deposited parent materials lead to formation of alluvium soil such as an Oakleaf which is dominated by a sandy fraction, and Tukulu soils which have agricultural potential in the EC. Furthermore, in semi-arid areas where low rainfall is experienced, soils formed from shale and mudstone parent materials tend to be highly erodible hence, crop cultivation is not recommended. These soil forms include, Hutton (eutrophic), Glenrosa, Swartland, Sterkspruit and Estcourt. In high rainfall and sub-humid areas, dolerite parent materials result in Hutton (dystrophic), Clovelly, Shortlands, and Bonheim soil forms.

Mandiringana *et al*. (2005) further advanced that problems arising from cultivation practices such as continuous tillage, mono cropping and residue removal cause SOC levels to fall below 1% equivalent to less than 10 g $kg^{-1}$ in the 0-20cm soil layer. Mouldboard plowing, which is the dominant tillage method in traditional farming is used in seedbed preparation, weed control, increasing water infiltration and burying of crop residues. Tillage incorporates organic matter into the soil at the cost of disrupting large soil aggregates thus, making SOC and soil nitrogen more susceptible to mineralization (Gupta Choudhury *et al.,* 2014). For instance, a study conducted by Higashi *et al*. (2014) examined tillage management systems and cover crops effect on changes in SOC. The results showed that, tillage had the effect of reducing SOM such that, when the soil was disturbed aeration improved and, subsequently increased mineralization of SOC and soil organic nitrogen (SON) of incorporated crop residues.

According to Cook and Weller (2004) continuous monocropping reduces biomass production through reduction in dry matter yields due to greater disease and pest inoculum as well as, loss of soil fertility due to nutrient mining and depletion of SOM. On the other hand, Tagar and Adamowski (2015) highlighted that, fallowing reduces soil aggregation as compared to continuous cropping by decreasing the amount of crop residue which is returned to the soil and by increasing SOM mineralization due to enhanced microbial activity.

#### 2.3.1. Role of soil organic carbon in soil fertility

According du Preez *et al*. (2011), soils in South Africa comprise of SOC levels that vary between 0.1 and 0.9%. A greater proportion (58%) of the soils in South Africa have SOC levels of less than 0.5%, and only 4% of the soils contain more than 2% of SOC (du Preez *et al*., 2011). This means that, about 38% of South African soils contain SOC levels between 0.5 and 2%. Hence, there is an urgent need for sustainable strategies to improve SOC in South African soils. Reason being, depletion of SOC is accompanied with soil erosion and loss of nutrients such as N, P, and Sulphur (Mandiringana *et al*., 2005). Soil organic carbon is important for stabilization of soil aggregates as this gives the soil the capacity to withstand erosion (Parwada and van Tol, 2016). Soil erosion usually accompanies loss of soil nutrients and hence, maintaining or improving SOC levels can indirectly improve soil fertility (Mandiringana *et al*., 2005).

Van Averbeke *et al*. (2004) also underline the fact that, direct SOC can supply soil with nutrients. In other words, application of livestock manure supplies SOC, as well as nutrients such as N, P and K (Mkile, 2001). On the other hand, efforts to mitigate declining SOC in the EC smallholder farming included application of cattle manure (Mkile, 2001), goat manure (Gichangi, 2007) and compost (Mupondi, 2010). Although application of manure to improve SOC and soil fertility has been utilized in the past, the problem is that, like all other fresh organic amendments, manure tends to mineralize rapidly (Calderon *et al*., 2015).

## 2.4. Conversion of biomass to biochar and its application

Biomass is converted to biochar through a process called pyrolysis (Laird *et al*., 2009). Pyrolysis is a thermochemical process whereby organic substances are broken down at temperatures ranging from 350-1000$^{o}$C in a low-oxygen (<2%) environment (Brewer *et al*., 2011). It is characterized as slow (<400°C), fast (> 400°C) and flash pyrolysis (400 - 650°) (Laird *et al*., 2009).

**Table 2.1:** Overview of pyrolysis methods with regards to biochar yield

| Process | Average Temperature ($^{o}$C) | Average time | Biochar |
|---|---|---|---|
| Slow pyrolysis | <400 | Minutes to days | 30-35 |
| Fast pyrolysis | >400 | 1-30s | 10-30 |
| Flash pyrolysis | 400-650 | 0.1-2s | <60 |

References (Adapted from Laird *et al*., 2009; Meyer *et al*., 2011)

Spokas *et al*. (2011) described slow pyrolysis conditions as having slow heating rates (1-20°C min$^{-1}$). The reaction time in slow pyrolysis ranges from minutes to days with an output yield of biochar (35%) by mass which is higher compared to other methods (Meyer *et al*., 2011). Fast pyrolysis is associated with rapid heating (up to 1000°Csec$^{-1}$) in the absence of oxygen (Brewer *et al*., 2011). Technically, this occurs in a continuous flow system with yields ranging between 50-70 % of bio-oil, 10-30 % biochar and 15-20% syngas (Laird *et al*., 2009). Laird *et al*. (2009) further contends that, flash pyrolysis which operates under pressure ranging from atmospheric to high pressure results in quick heating of biomass (in seconds or less). This process can be optimized for either biochar production (with up to 60 % biochar yield) or bio-oil production (with up to 70 % bio-oil yield) (Laird *et al*., 2009).

Slow pyrolysis method for biochar was adopted in this study because of its simplicity in application and cost effectiveness in smallholder production. Different types of slow pyrolysis reactors have been proposed and some have been historically used in charcoal production. In ancient times (500-8000 years ago) biochar "*charcoal*" was produced by "pit" or/ "trench" method by early human populations (Lehman and Joseph, 2009; Lehmann *et al*., 2006). Slow pyrolysis can be done in reactors such as brick or earth kilns, metal (drum) kilns and cook stoves (Torres Rojas *et al*., 2011). However, small-scale biochar production technologies have different operating conditions and are diverse. For example, as a charred substance or upon soil application, biochar may look similar but, its application is sorely on the feedstock material.

### 2.4.1. Effects of feedstock characteristics

Laird *et al*. (2009) underscored the importance of biomass feedstock properties in influencing the resultant pyrolysis products. Feedstock with high ash content results in decreased carbon content in the resulting biochar (Gaskin *et al*., 2008). By contrast, feedstock with a high holocellulose/lignin ratio increases volatile yields and decreases char yield (Hodgson *et al*., 2011). Thus, feedstock composition affects the quality of biochar. Feedstock materials containing higher nutrients, such as animal manure, can result in biochars with high nutrient content as compared to plant feedstocks that, are mainly composed of cellulose, hemicelluloses, lignin, and some inorganic compounds (Singh *et al*., 2010). For instance, poultry litter manure, is composed of large variations in poultry species, age and feeding scheme. Hence, manure nutrient compositions vary and change on daily basis. In support of the above assertions, a study by Revell *et al*. (2012) concluded that, poultry litter biochar had a carbon content of 27%. A study conducted by Chan *et al*. (2008) found out that, the carbon content of poultry litter biochar used had 38% of carbon content. Thus, the variation in both studies infers that there is need for characterization of all biochar materials.

### 2.4.2. Characteristics of biochar

Biochar composition consists of (i) stable or fixed carbon, (ii) labile carbon and other volatile compounds, (iii) moisture, and (iv) ash components that are highly variable due to the feedstock material (Schmidt *et al*., 2011; Lehmann *et al*., 2006). The C and N concentration of biochar from plant-based feedstocks was found to increase due to the feedstock. Concentrations may decrease in manure-based feedstocks because fewer volatile elements are concentrated during pyrolysis and are lost during the process (Singh *et al*., 2010). Although some N is lost as gas through volatilization during heating, about 50 % of N is locked up in the biochar matrix while, minerals such as Ca, K and P and metals concentrate in the biochar during pyrolysis (Singh *et al*., 2012). During pyrolysis, P is reported to undergo transformation where labile P becomes incorporated in Ca-P or Mg-P ionic compounds (Christel *et al*., 2014; Wang *et al*., 2015). Biochar produced from manure feedstocks has the capacity to enhance chemical properties considerably owing to its nutrient content value. In addition, a recent study carried out by Lopez-Capel *et al*. (2016) indicated that biochar from woody feedstocks had roughly 5-10%, straw feedstocks 10-15% and digestate from anaerobic digestion 21%. The stable carbon contents are relatively high in biochar produced from plant materials feedstocks, but the ash which is rich in mineral elemets Ca, Mg, Na, N, P and K contents are much higher in manure based biochar especially, poultry litter biochar (Chan *et al*., 2008). Hence, plant material biochar have high C/N ratio as compared to that from poultry, pig, and cattle manure (Lopez-Capel *et al*., 2016).

During pyrolysis, oxygen, hydrogen, sulphur and N are driven off from the biomass through heating followed by reorganization of the chemical structure (Schimmelpfenning and Glaser, 2012). As a result, loss in oxygen and hydrogen is higher than loss in carbon (Schimmelpfenning and Glaser, 2012; Amonette and Joseph, 2009). Hence, carbon is more concentrated or higher in biochar than the feedstock biomass material. In addition, biochar is resistant to mineralization in soil due to its re-arrangement in molecular structure. On the other hand, fresh biomass contains labile and recalcitrant molecules. Schmidt *et al*. (2011) states that fresh organic materials contain little or no highly stable molecules. Singh *et al*. (2012) further posits that microorganisms easily decompose labile molecules and a farmer applying fresh amendments to his fields will see little of that carbon remaining after years or months of its application. Biochar contains a network of tiny tunnels or pores, some of which, connect to the outside while, others are closed off in freshly produced biochar (Glaser *et al*., 2000). This makes biochar to behave like a sponge when amended to the soil. Biochars structure comprises of micropores, mesopores and macropores and can easily hold a lot of water up to six times its weight (Stella Mary *et al*., 2016). Thus, biochar produced from plant feedstocks has pores derived from xylem and phloem vessels that are large (macro) and are > 50 micrometers in diameter. This implies that, amendment of biochar in the soil improves water holding capacity of the soil. However, when water enters the micropores, the manner in which the biochar holds the water molecules is so strong such that, it becomes difficult for plant roots to extract it (Schimmelpfenning and Glaser, 2012). The pH range of biochar is between 8 and 11. The ash in biochar washes out when placed in water. High ash content biochar from manures, sludge and anaerobic digestate normally and indicate pH values above 9, whilst biochar from plant materials can exhibit a pH value of 6 or 7.

### 2.4.3. Effects of biochar on soil properties

Biochar addition to soil can produce changes in the soil's chemical and physical properties including nutrient availability, pH, bulk density, and water holding capacity (Sohi *et al*., 2010). Long-term influence of biochar soil amendments are realized though the stabilization of humic substances (Lehmann and Joseph, 2009). Stabilization is achieved through the masking effect that the biochar has on the decomposition of humic acids. For example, the biochar acts as a defence mechanism that makes organic matter physically inaccessible to microbes through its numerous and tedious network of porous tunnels which they encounter first. Cheng *et al*. (2008) supported this mechanism which resulted in the formation of Amazonia soils of the *terra preta*, which had higher SOM levels. Chan *et al*. (2008) argue that, the chemical changes in soil after biochar application reflects the properties of the biochar being applied. However, several researchers namely Glaser *et al*. (2002), Lehmann *et al*. (2006), Rondon *et al*. (2007) and Sohi *et al*. (2009) have found that biochar soil amendment influences soil properties through three primary mechanisms that include:

(i) direct alteration/or modification of soil chemistry through biochar's intrinsic characteristics (elemental and compositional make up) which includes liming effect in acidic soils, direct nutrient addition through biochar and nutrient use efficiency,

(ii) allocation of chemically active surfaces that modify the dynamics of soil nutrients or otherwise catalyze useful soil reactions, and

(iii) modification of physical soil properties that leads to increased root growth and/or water and nutrient retention and plant availability.

These mechanisms are supported with increases in total C, total N, pH, CEC, available P, and exchangeable cations (e.g. Ca, Mg, Na, and K) in soil (Chan *et al*., 2008; Van Zwieten *et al*., 2010). Similarly, Major *et al*. (2010) found that biochar addition increases available Ca, Mg, and pH in soil. A convergence of literature on short-term studies shows that biochar application can significantly influence soil pH and EC (Jien and Wang, 2013), nitrogen (ammonium and nitrates), and organic carbon (Kongthod *et al*., 2015; Darby *et al*., 2016; Zhu *et al*., 2014), phosphorus (Kongthod *et al*., 2015).

*2.4.3.1. Nutrient release*

The nutrient composition which originate from the feedstock biomass is preserved in the ash fraction of the biochar, including N, P, K, S, Ca, Mg, Mn, Fe, and Zn which are required for plant growth (Chan *et al*., 2008). It has been observed that, after biochar application total C, organic C, total N, available P, and exchangeable cations Ca, Mg, Na, and K increase while, available Al decreases in soil (Kongthod *et al*., 2015; Darby *et al*., 2016; Zhu *et al*., 2014). The advantage of biochar being added to fresh organic amendments is that, biochar is resistant to microbial degradation but, the relationship between biochar C/N ratio and mineralization/immobilization is different to that of fresh organic amendments (Cayuela *et al*., 2013). For example, if an organic amendment with a high C/N ratio is added to the soil, it results in microbial flourish, decomposition of organic matter and nutrient release at the expense of mineral N accessibility to plants. These finding are supported by a study carried out by Darby *et al*. (2016) which revealed that, though application of compost significantly increased soil ammonium concentrations, compost-biochar mixture and biochar did not significantly influence N mineralization.

Phosphorus in biochar is slowly released because of the transformations that occurs during pyrolysis (Liang *et al*., 2014). Hence, pyrolysis of manure is an option to immobilize the P and transforms it as slow release P fertilizer. For instance, observations were made that, P immobilized after hydrothermal carbonization for cow manure. This is an indication that, the water and Mehlich 3 extractable P decreased from approximately 50% and 65% in the raw feedstock to approximately 8% and 20% after carbonization (Dai *et al*., 2015).

*2.4.3.2. Soil pH and field capacity*

Martinsen *et al*. (2015) observed that the pH of a soil increased with biochar addition. The ash content of biochar is primarily responsible for the modification of the soil's pH. Biochars with high mineral ash content have more of an effect on the pH of a soil. Furthermore, since biochar is of alkaline pH it may alter the pH of the soil in a favorable direction for most crops (Chan and Xu, 2009) as shown in table 2.2. Additionally, biochar application may provide positive changes to the water holding capacity of sandy loam soils (Mohamed *et al*., 2016).

### 2.4.4. Biochars effect on crop growth

*2.4.4.1. Biomass yield*

A number of studies carried out indicate that there is a positive response of crop growth to biochar application (Uzoma *et al*., 2011; Schulze and Glaser, 2012; Zhu *et al*., 2014). For example, one of the studies revealed that, maize grown for 46 days had biomass weights ranging from 7.1 to 14.9 g $pot^{-1}$, while biomass increases in biochar treatments were significantly related SOC, total N, total P and available N and P (Zhu *et al*., 2014). On the other hand, Van Zwieten *et al*. (2010) grew wheat in a ferrosol soil and found no significant differences on biomass yield in the absence of fertilizer. However, when fertilizer treatment was included, significant increases were obtained, supporting the notion that biochar is not a fertilizer. Meanwhile, a study by Chan *et al*. (2008) obtained significant radish biomass yields (up to 96%) in the absence of N fertilizer with application of poultry litter biochar in a glasshouse experiment (Table 2.2). Thus, biomass yield improvements were obtained at low application rate of (10 t $ha^{-1}$) rate and were increasing proportionately with increases in biochar application rates up to 50 t $ha^{-1}$.

*2.4.4.2. Early crop establishment*

The influence of biochar from biosolids, corn stover, eucalyptus, fresh pine and willow amendment on seedling establishment showed no significant differences on maize seedling germination (Free *et al*., 2010). However, biochar types application in different soil types resulted in significant differences on seed weight, coleoptile weight and length. Application at any rate did not result in any significant differences on root weight, and coleoptile length (Free *et al*., 2010). In Table 2.2, Uzoma *et al*. (2011) obtained higher maize stem length and increased number of leaves as cattle manure biochar application rate was increased. The influence was found to be highly correlated with maize grain yield and nutrient concentration at harvest (Uzoma *et al*., 2011). Furthermore, the review of related literature shows that biochar amendments helps in increasing pH, organic C, N, P Ca, Mg, Na, K, water holding capacity and carbon sequestration which helps in the building up of soil fertility. The application of biochar to soil also promotes plant growth.

**Table 2.2:** Effects of livestock manure biochars applied as a soil amendment

| Biochar type | Experimental conditions | Effects in soils | References |
|---|---|---|---|
| Cow manure | Greenhouse pot experiments were carried out in a sandy soil with biochar at 0, 10, 15 and 20 t/ha soil mixing rates. Maize was grown in the pots for 85 days receiving adequate fertilizer, moisture was maintained at field capacity. Growth was monitored weekly with leaf number and stem length readings taken. Harvest was done at 85 days of growth and grain yield was determined. | Influenced the soils properties such as hydraulic conductivity, pH, total C, total N, Oslen-P, exchangeable K, Ca and Mg and CEC. Hydraulic conductivity was decreased, whilst carbon, nitrogen and phosphorus contents of the sandy soil were increased with increasing biochar application rate | Uzoma *et al*. (2011) |
| Poultry litter | Radish test crop was planted in a glasshouse pot experiment grown in an Alfisol soil amended with biochars produced at 450 and $550^0$C. Biochars were applied at 0, 10, 25, and 50 t/ha mixing rates, with and without nitrogen application (100 kg N/ha). Pots were maintained at field capacity throught the duration of the experiment. | Significant increases in soil chemical such as EC pH, organic carbon and mineralization of nitrogen. The improvements were differed between the biochar treatment amendments. Biochar at $550^0$C had the most higher soil chemical improvements. | Chan *et al*. (2008) |
| Pig manure | An incubation experiment using silt loam and clay soils in 250 mL amber bottles containing 50 g soil and manure biochar incorporated at rates of 0 (CK), 0.5% (M1 treatment) and 1.5% (M2 treatment) by mass. The containers were covered with tinfoil, and kept aerated in the incubator at 25 $^0$C for 3, 7, 14, 28, 42, 63, 84, 98 days. | Amending pig manure biochar significantly improved CEC and nutrients in the soils. Olsen-P was increased with the addition of biochar but contents of P did not change much with biochar treatments during the incubation time. | Jin *et al*. (2015) |

Therefore, biochar has the potential to improve crop productivity which is declining in smallholder farming. There is need for further research on the production of biochar using local manures as well as testing its amendment potential in local soils for the improvement of both fertility and crop productivity. Currently, there is a dearth of research studies which indicate how biochar amendment affects the growth and biomass yield of plants grown on the biochar amended soil. Factors such as feedstock type and pyrolysis conditions, influence the characteristics of the resulting biochar which in turns impacts on the potential of biochar to alter soil properties and improve crop productivity.

### 2.5 Conclusion and recommendation

The EC is dominantly characterized by dryland maize-mixed farming system in which livestock feed on crop residues and the manure generated by livestock is used to fertilize croplands. Literature has shown that, the soils used for crop cultivation are of low fertility especially SOC. Therefore, to boost productivity alternative strategies such as the conversion of manure and crop residues to biochar is motivated. The extant literature further highlights that manures are a potential feedstock for biochar production since crop residues are fed to livestock. Conversion via slow pyrolysis method is of interest due to its proportionate distribution of outputs and easiness in operation. Farmers can utilize smallholder pyrolysis which is a cheap and affordable method of producing biochar.

# 3. FARMING SYSTEM, AVAILABILITY AND UTILIZATION OF LIVESTOCK KRAAL MANURES IN RAYMOND MHLABA MUNICIPALITY, EASTERN CAPE PROVINCE, SOUTH AFRICA


## Abstract

Smallholder agriculture in Africa is dominated by both livestock rearing and subsistence smallholder cropping. However, information of farmers cropping with the utilization of livestock manures for fertility management among the Raymond Mhlaba Municipality smallholder farmers is outdated. A survey was conducted to explore the farming systems, availability, and utilization of kraal manure in the Raymond Mhlaba Municipality, Eastern Cape, South Africa. One hundred and fourteen households were interviewed using semi-structured questionnaire surveys, while field assessments were also used to gather data from five villages of the Raymond Mhlaba Municipality. Social demographic characteristics of the household revealed that, 69.4% of the household heads interviewed were females and on average 4.89±1.50 persons were resident per household. The literacy levels indicated that 70.14% of the interviewed heads had attended school and only 29.86% had no formal education. Furthermore, it emerged that livestock sales was the most dominant source of income. The farmers interviewed had communal land tenure system with livestock rearing being the dominant agricultural practice. On average households kept 9.24±8.21 sheep, 9.37±8.15 goats, 7.95±7.66 cattle, and 9.02±9.47 chickens. Arable land entitlement was responded by 94 (82.5 %) households who had smallholdings ranging from 0.5 ha – 2 ha which was allocated for cropping. The mean sizes for homegardens were 0.25±0.2 ha for homegardens while, the outfields were 0.89±0.3 ha. The study also found out that only 55

(48.3 %) of the 94 (82.5 %) households were currently utilizing their smallholding land for cropping. The crops grown were maize, cabbages, spinach, and potatoes.

The findings of the study also indicated that maize was the most commonly grown crop by most households. In addition, the households participating in the study estimated that the total manure production was 2.9 t year$^{-1}$, 0.82 t year$^{-1}$, 0.04 t year$^{-1}$, and 0.8 t year$^{-1}$ from cattle, goat, chicken, and sheep, respectively. The results further revealed that, 40 (35.1 %) of the 55 (48.3 %) households that were growing crops, they utilized livestock manure for soil fertility management. For instance, most of the respondents indicated that, they applied goat manure in homegardens by band placing method. The application rates ranged from 500kg–1200kg and on average the mean household manure application in the homegardens was 644±181kg and 719±182kg in the outfields. The sizes of the smallholdings were homegardens (mean size 0.25±0.2 ha) and outfields (mean sizes 0.89±0.3 ha). The homegarden size and outfields had a significant ($P<0.05$) effect on the likelihood of a farmer adopting manure utilization. The foregoing results from the study imply that, the identification of manure utilization and factors influencing its use, show that manure can be used efficiently if alternative ways for utilization are suggested in the EC.

*Keywords*: Livestock rearing, cropping, maize, manure utilization, soil fertility

## 3.1. Introduction

Agricultural production in the central Eastern Cape (EC) integrates rearing of cattle, sheep and goats with subsistence growing of crops (Yoganathan *et al*., 1998; van Averbeke and Bennet, 2007). Subsistence crops such as maize, beans and pumpkins as well as, vegetables including cabbage, spinach, onions and peas are grown on individual smallholdings with sizes between 0.5 ha - 3 ha (van Averbeke *et al*., 2008; Manyevere *et al*., 2012). Soil infertility is a major constraint that affects crop productivity in the central EC (Mandiringana *et al*., 2005). Many of the farmers are 'resource poor' and lack financial resources to buy inorganic fertilizers and as a result, usage is low and estimated at 9 kg $ha^{-1}$ of NPK (Yoganathan *et al*., 1998). Alternative strategies to improve the value of fertilizer found locally on smallholder farms such as livestock manures and farmyard manure have yielded improvements in the EC (Yoganathan *et al*., 1998; Mnkeni and Mkile, 2006; van Averbeke *et al*., 2008). However, there are few studies relating to livestock manure availability and utilization in the EC and a lack of recent information that supports manure utilization in cropping. The last research in the central EC was carried out by Yoganathan *et al*. (1998). However, the current situation shows that, there has been a paradigm shift because of the South African government move to support black smallholder farmers.

According to Mkile (2001) and Salomon (2011), livestock such as cattle, sheep and goats in communal areas are kraaled overnight for security. Livestock graze in communal rangelands during the day and in the dry season, livestock graze on crop residues (Yoganathan *et al*., 1998). Manure that drops during grazing provides fertility for the rangelands and cropping lands. Livestock penning (kraaling) to confinements close to households allows for manure accumulation (Yoganathan *et al*., 1998; Mkile, 2001). A study conducted by Mnkeni and Mkile (2006) in the Transkei estimated that the total manure dry matter production was 1.6 million tonnes year$^{-1}$. However, local studies conducted in central EC failed to provide information on the availability of livestock manure (Yoganathan *et al*., 1998). Manure utilization is known to improve soil organic matter and soil fertility and is an important resource in crop production (van Averberke *et al*., 1998; Mandiringana *et al*., 2005). A study by Yoganathan *et al*. (1998) conducted in the central EC showed that kraal manure application in fields ranged from 3 to 1820 kg ha$^{-1}$. The same study by Yoganathan *et al*. (1998) further highlighted that optimum kraal manure application for cabbage production was 20 t ha$^{-1}$ per cropping season. These reults were an indication that, application of kraal maure was not in excess, an implication that farmers were reluctant to utilize kraal manure as a fertilizer resource. The results ememrging from a study conducted by Mkile *et al*. (2001) in the former Transkei highlighted that the available manure was of varying nutritional composition, where goat manure had the highest N, P, and K content followed by sheep and cattle manures. The nutrient contents ranged from, 9.9 – 16.7 g kg$^{-1}$ N, 2.0 – 3.6 g kg$^{-1}$ P, and 17.2 – 23.7 g kg$^{-1}$ K (Mkile *et al*., 2001).

Research studies carried out in the EC with livestock manure utilization from goat (Gichangi, 2007), sheep (Mhlontlo *et al*., 2007), and cattle (Nciizah, 2011) obtained positive results on soil fertility and plant growth improvement. Sheep manure application at 10 t ha$^{-1}$ in maize intercropped with amaranthus accession resulted in increased nutrient uptake and growth yield of the vegetable as compared to inorganic N, P, and K fertilization at 150 kg $ha^{-1}$. Therefore, understanding the quantities of manure soil fertility amendments and utilization could open up other avenues for effective use in crop productivity. Manyevere *et al*. (2012) obtained a general decrease in crop cultivation and land abandonment because of soil infertility in the Raymond Mhlaba municipality. This study was conducted so as to obtain manure quantities and utilization to assist in developing ways to enhance manure use.

**Objectives of study were to**:

(i) Determine farmer crop and livestock production in selected villages of Raymond Mhlaba Municipality.

(ii) Determine manure quantities available and their utilization in cropping.

(iii) Determine factors influencing utilization of livestock manure by farmers involved in cropping

**Hypotheses**:

(i) Farmers crop and livestock production do not differ in villages selected by researcher.

(ii) There is no difference in available manure quantities and utilization in cropping.

(iii) Factors influencing utilization of livestock manure by farmers involved in cropping are not different.

## 3.2. Materials and methods

### 3.2.1. Description and location of study site

The survey was conducted in the Raymond Mhlaba Municipality. The municipality has a total land area of 3 725 $km^2$ with a semi-arid climate. The study site was purposely selected based on studies by Hebinck and van Averbeke (2007a) and Musemwa *et al*. (2008) who classified its livelihood as dependance on subsistence agriculture which is premised on a mix of crops and livestock. It has a population of 127 115 (Stats SA, 2011). According to Mc Cain (2005) about 72 % of the population live below poverty datum line in its 182 rural villages with 35 355 households (Stats SA, 2011). The average temperatures range between $7^{o}C$ to $22^{o}C$ (minimum and maximum), and has an annual average rainfall of ± 525mm which is received mostly in summer (Institute for Soil, Climate and Water, 2008).

### 3.2.2. Selection of study sites

Five villages (Table 3.1) were randomly selected from those within a 30 km radius of the University of Fort Hare for logistical reasons.

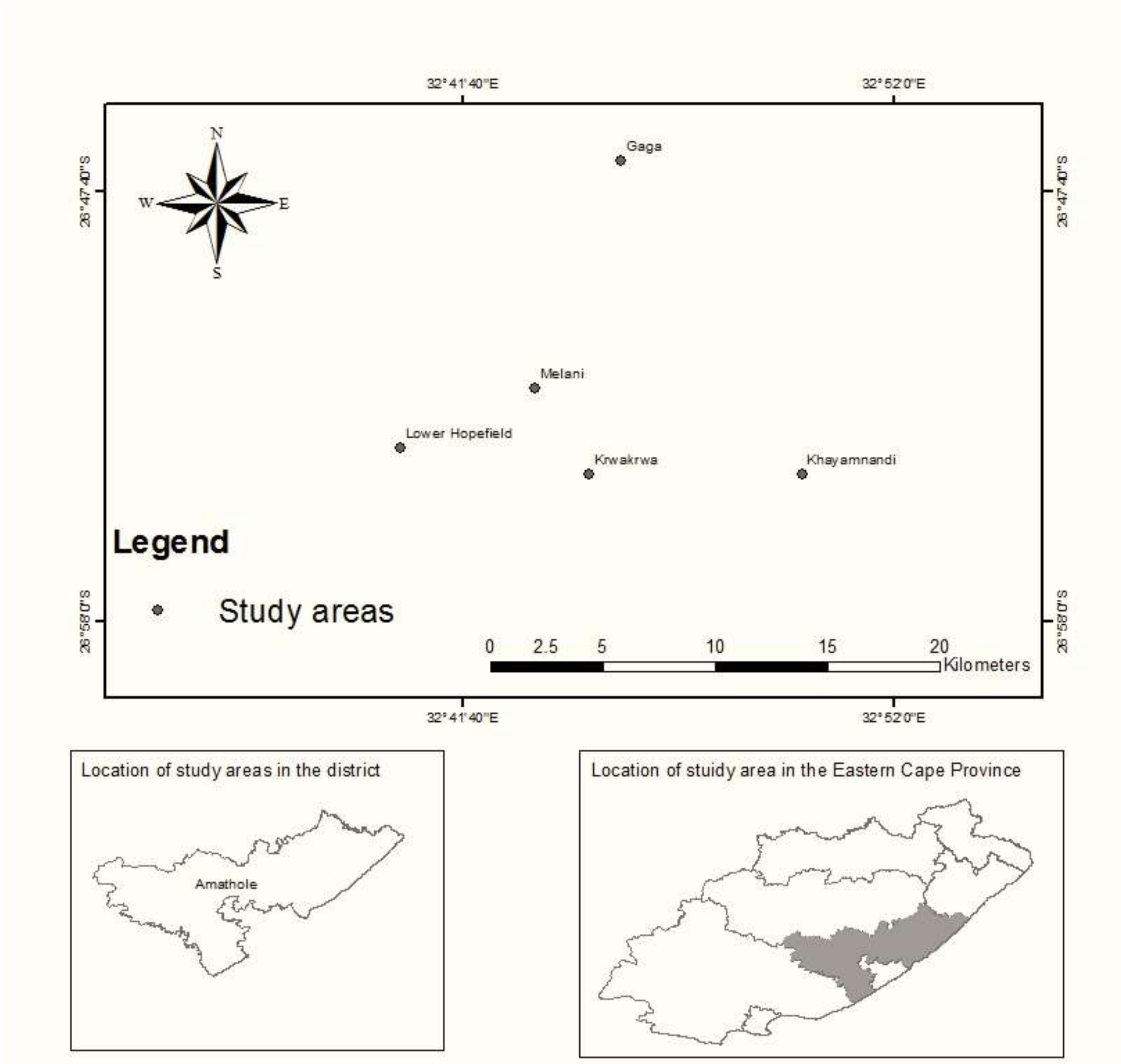


**Figure 3. 1:** Map of Eastern Cape Province showing the location of the district and selected villages in the Raymond Mhlaba Municipality where interviews were administered to crop-livestock farmers.

**Table 3.1:** GPS coordinates and population in five villages selected for the survey on farming systems and availability of manure

| **Study sites** | **GPS Coordinate** | **Population census (Stats SA 2011)** |
|---|---|---|
| Lower Hopefield | 32°40'9.72"S 26°53'49.39"E | 527 people and 156 households |
| Gaga | 32°45'26.63"S 26°46'56.11"E | 588 people and 170 households |
| Khayamnandi | 32°49'48.36"S 26º54`26.79"E | 1342 people and 348 households |
| Krwakrwa | 32°44'40.73"S 26°54'26.79"E | 777 people and 291 households |
| Melani | 32°43'24.17"S 26°52'24.28"E | 783 individuals and 279 households |

### 3.2.3. Conduct of the survey

*3.2.3.1. Design of the questionnaire instrument*

The survey design commenced with a review of background information available in the literature on farming systems in Raymond Mhlaba Municipality. Informal interviews were conducted with key informants who included officials of the Department of Agriculture in Alice, traditional leaders and prominent farmers in the municipality. Trained Xhosa speaking enumerators assisted in conducting the informal interviews to ensure uniformity in interpretation of the gathered data. The informal interviews were used to formulate research questions for a quantitative survey.

*3.2.3.2. Household questionnaire survey*

A semi-structured questionnaire (Appendix 1) was prepared and pre-tested before its administration in five villages that were selected for the survey. All the questions were directed to the head of the household. In the absence of the head, any other household member involved in decision making with regard to management of the farm enterprise was requested to be the respondent. The interviews were conducted with the help of five trained enumerators and the native language of the respondetns which is, isiXhosa was used. Interviews were conducted privately with consent from the respondents. The following information was obtained: household demographic characteristics (gender, source of income, education, and household size, and household age distributions). Livestock data captured included livestock types and livestock numbers per type. Data on the sizes of land which was allocated to the farmers for cropping, the types of crops grown, and quantities of manures used by farmers in crop production was also captured. Farmers local units of measurements (for manures) were standardized into kilograms.

### 3.2.4. Determining household livestock manure production

Potential livestock manure production was estimated from livestock numbers (Table 3.2) from the sites of the study. The quantity of total manure produced per year per household was calculated based on the number of TLU and quantity of manure produced daily from each livestock TLU on dry matter (DM) basis. The calculations were made on dry matter basis and did not take animal beddings and/or feed refusals into account. This was done by utilizing equations and transfer functions derived from secondary information that relate manure production to livestock types and numbers (Table 3.2).

**Table 3.2:** Assumptions made in estimating the potential manure production in the study

| Assumption | Reference |
|---|---|
| TLU conversion factors for livestock categories. Cattle = 0.7 sheep and goats = 0.1, poultry = 0.01 | FAO, (2014) |
| Poultry produces 0.5 kg of fresh manure (70% moisture) per yea per kg of body weight. In the study a chicken with a TLU of 0.01 was assumed to produce 10 g fresh manure per day (manure dry matter of 3( %) | FAO, (2004) |
| Cattle produces 3.3 kg of dry manure (DM) per day per TLU | Abebe, (2015) |
| Sheep and goats produces 2.4 kg of dry manure (DM) per day pe TLU | Onduru *et al*. (2008) |

TLU = 250 kg live animal weight (Jahnke, 1982), Body weight of average range from 1 kg-2 kg (Indigenous poultry breeds in SA)

### 3.2.5. Statistical analysis

Data collected from the questionnaires was analyzed using IBM statistical package for social sciences, SPSS version 23 (SPSS, Inc., Chicago, IL, USA) (SPSS Inc., 2015). Descriptive statistics were generated to represent respondents' opinions on various aspects of socio-economic demographics, farming systems and manure utilization. One-way ANOVA and t-tests were carried out to test significant differences of factors. Binary logistic regression was used to determine household factors influencing decision on manure use. According to Mukai (2017), a probability associated with the farmers willingness to manure is desired. The following mathematical representation of the binary logit model was used.

$$\log[P_u /(1-P_u)] = \alpha + \sum_{i=1}^{1} \beta i X i + \sum_{j=1}^{2} \beta j X j + \cdots \sum_{k=1}^{5} \beta k X k + \varepsilon$$

Where:

$P_u$ = probability of a household using manure;

[1-$P_u$] = probability of a household not using manure;

α = intercept;

$\sum_{i=1}^{1} \beta i X i \ldots \sum_{k=1}^{5} \beta k X k$ = linear regression coefficients of household head gender, household size, household labour unit 1 (18-44 yrs), labour unit 2 (45-60 yrs), labour unit 3 (>60yrs), household outfield farm size (ha), and household homegarden size (ha);

ε = random residual error.

*3.2.5.1. Description of variables specified in the model*

*Household head gender*- Men and women engage in different activities at household level as defined by the African historical cultural domain. Household head gender was conjectured to influence the likelihood to be engaged by female or male headed families in as far as manure use was concerned. Accroding to Waithaka *et al*. (2007), households headed by males were therefore, expected to participate in manure use more than female headed households.

*Household size and labour units*- Household size was measured by the number of family members in the household. Household size would be expected to determine the labour force available to use manure (Waithaka *et al*., 2007).

*Farm size*- Manure use was also expected to be influenced by the size of the`farm fields which are categorized as outfield and homegarden. The larger the farm field and the more distant from the household, the lower the likehood of manure use (Mkhabela and Materechera, 2003). Therefore, smallholder farmers are more likely to engage in manure use if farm sizes are smaller and closer to households.

## 3.3. Results

### 3.3.1. Household socio-economic demographics

#### *3.3.1.1. Family size and age distributions of the respondents*

The results showed that from the 114 households interviewed (Table 3.3), the majority (64.9%) of the households in the Raymond Mhlaba Municipality were female headed and 35.1% of the households were found to be headed by males. The findings of the study indicated that amongst the female-headed households, Melani had 69.6% while, Khayamnandi had the lowest (61.9%) of female-headed households.

**Table 3.3:** Proportions of female and male-headed households interviewed in five villages selected for survey in Raymond Mhlaba Municipality

| Village | Number of respondents | Gender distribution | | | |
|---|---|---|---|---|---|
| | | Male | | Female | |
| | | Frequency | % | Frequency | % |
| Lower Hopefield | 22 | 8 | 36.4 | 14 | 63.6 |
| Gaga | 24 | 9 | 37.5 | 15 | 62.5 |
| Khayamnandi | 21 | 8 | 38.1 | 13 | 61.9 |
| Krwakrwa | 24 | 8 | 33.3 | 16 | 66.7 |
| Melani | 23 | 7 | 30.4 | 16 | 69.6 |
| Total | 114 | 40 | 35.1 | 74 | 64.9 |

The family size and age structure of households in the study is shown in Table 3.4. Overall, household size for all the villages was 4.89±1.50 persons per household.

**Table 3.4:** Mean household size and number of members per age group distribution in households interviewed in Raymond Mhlaba Municipality

| Household characteristic | Mean household ± SD | | | | | |
|---|---|---|---|---|---|---|
| | **1 (n=24)** | **2 (n=21)** | **3 (n=23)** | **4 (n=24)** | **5 (n=22)** | **Overall (n=114)** |
| Family size | 5.14±1.73 | 4.38±1.35 | 5.05±1.16 | 5.17±1.74 | 4.74±1.39 | 4.89±1.50 |
| <6 years | 0.86±0.83 | 0.58±0.72 | 0.76±0.77 | 0.67±0.64 | 0.83±0.83 | 0.74±0.75 |
| 7 – 17 | 1.27±0.88 | 0.96±1.08 | 1.00±0.78 | 1.17±1.01 | 0.78±0.74 | 1.04±0.91 |
| 18 – 44 | 1.18±1.40 | 1.17±0.82 | 1.29±1.00 | 1.67±1.20 | 1.17±0.65 | 1.30±1.05 |
| 45 – 59 | 1.14±0.71 | 1.04±0.75 | 1.14±0.79 | 0.96±0.81 | 1.17±0.72 | 1.09±0.75 |
| >60 | 0.68±0.57 | 0.71±0.75 | 0.86±0.48 | 0.79±0.66 | 0.78±0.52 | 0.76±0.60 |

Significance level 1 = Lower Hopefield, 2 = Gaga, 3 = Khayamnandi, 4 = Krwakrwa, 5 = Melani

There was no significant ($p \geq 0.05$) differences for the means of household family size and these ranged between 7 – 17, 18 – 44, 45 -59, and > 60 age groups.

*3.3.1.2. Household head literacy level*

Literacy rates are shown in Table 3.5. On average, 70.14% of the respondents attended school whilst, 29.86% had no formal education. The results from the interview indicated that the highest education level attained was 7 years (39.38%), 12 years (28.1%), and > 12 years (2.66%) (Table 3.5). The highest number of farmers that had no formal education was (40.9%) and these were found in Hopefield village.

**Table 3.5:** Mean educational status of household heads interviewed in Raymond Mhlaba Municipality

| Variables | Villages | | | | | |
|---|---|---|---|---|---|---|
| | **1 (n=22)** | **2 (n=24)** | **3 (n=21)** | **4 (n=24)** | **5 (n=23)** | **Overall N=114** |
| None | 0.4±0.5 | 0.3±0.4 | 0.2±0.4 | 0.3±0.5 | 0.3±0.5 | 0.3±0.5 |
| % response | 40.9 | 25 | 23.8 | 29.2 | 30.4 | 29.86 |
| Primary | 0.2±0.4 | 0.5±0.5 | 0.5±0.5 | 0.4±0.5 | 0.4±0.5 | 0.4±0.5 |
| % response | 22.7 | 50 | 47.6 | 37.5 | 39.1 | 39.38 |
| Secondary | 0.4±0.5 | 0.2±0.4 | 0.2±0.4 | 0.3±0.5 | 0.3±0.4 | 0.3±0.5 |
| % response | 36.4 | 20.8 | 23.8 | 33.3 | 26.2 | 28.1 |
| Tertiary | - | 0.04±0.2 | 0.05±0.2 | - | 0.04±0.2 | 0.03±0.2 |
| % response | - | 4.2 | 4.8 | - | 4.3 | 2.66 |

Significance level 1 = Lower Hopefield, 2 = Gaga, 3 = Khayamnandi, 4 = Krwakrwa, 5 = Melani

*3.3.1.3. Livelihood sources*

The findings of the study showed that sources of income were seasonal jobs and crop sales. Table 3.6 shows the mean ranks of farmers' responses on sources of income they obtained for their livelihoods. The dominant livelihood in this study was from livestock sales and most of the income was also derived from the sale of sheep. Meanwhile, Gaga and Lower Hopefield (46%) had the highest proportion of household-head responses.

**Table 3.6:** Mean score (rank) of household sources of income in selected villages of Raymond Mhlaba Municipality

| **Source** | **Villages** | | | | | |
|---|---|---|---|---|---|---|
| | **1 (n=22)** | **2 (n=24)** | **3 n=21)** | **4 (n=24)** | **5 (n=23)** | **Overall N=114** |
| Selling goat | $0.05\pm0.2^{1}$ | - | $0.1\pm0.3^{1}$ | $0.04\pm0.2^{1}$ | $0.1\pm0.3^{2}$ | $0.06\pm0.2^{4}$ |
| % response | 4.5 | - | 9.5 | 4.2 | 13 | 6.1 |
| Selling sheep | $0.5\pm0.5^{6}$ | $0.5\pm0.5^{6}$ | $0.4\pm0.5^{6}$ | $0.4\pm0.5^{6}$ | $0.3\pm0.4^{6}$ | $0.4\pm0.5^{8}$ |
| % response | 45.5 | 45.8 | 38.1 | 41.7 | 26.1 | 39.5 |
| Selling cattle | $0.1\pm0.3^{3}$ | $0.04\pm0.2^{1}$ | $0.1\pm0.4^{3}$ | $0.04\pm0.2^{1}$ | $0.2\pm0.4^{4}$ | $0.1\pm0.3^{5}$ |
| % response | 9.1 | 4.2 | 14.3 | 4.2 | 14.4 | 9.6 |
| Selling crops | $0.05\pm0.2^{1}$ | - | - | $0.08\pm0.3^{3}$ | - | $0.03\pm0.2^{2}$ |
| % response | 4.5 | - | - | 8.3 | - | 2.6 |
| Gvt grant | - | $0.04\pm0.2^{1}$ | $0.1\pm0.4^{3}$ | - | $0.09\pm0.3^{1}$ | $0.05\pm0.2^{3}$ |
| % response | - | 4.2 | 14.3 | - | 8.7 | 5.3 |
| Pension | $0.2\pm0.4^{4}$ | $0.2\pm0.4^{4}$ | $0.1\pm0.4^{3}$ | $0.2\pm0.4^{4}$ | $0.1\pm0.3^{2}$ | $0.2\pm0.4^{6}$ |
| % response | 18.2 | 16.7 | 14.3 | 20.8 | 13 | 16.7 |
| Seasonal | - | $0.08\pm0.3^{3}$ | - | - | - | $0.02\pm0.1^{1}$ |
| % response | - | 8.3 | - | - | - | 1.8 |
| Salary | $0.2\pm0.4^{4}$ | $0.21\pm0.4^{5}$ | $0.1\pm0.3^{1}$ | $0.2\pm0.4^{4}$ | $0.2\pm0.4^{4}$ | $0.2\pm0.4^{6}$ |
| % response | 18.2 | 20.8 | 9.5 | 20.8 | 21.7 | 18.4 |

NB: The lower the mean rank score of an income source, the greater is its importance 1 = Lower Hopefield, 2 = Gaga, 3 = Khayamnandi, 4 = Krwakrwa, 5 = Melani

Emerging from the findings of the study, the househould survey indicated that 21% of the respondents in Krwakrwa depended on pensions while, 22% of the population of respondents in Melani said government grants where their major source of income. Crop production contributed a negligible percentage to household income in all the five villages.

### 3.3.2. Smallholder farming system in the Raymond Mhlaba Municipality

*3.3.2.1. Smallholding farm size distribution*

The results of the study indicted that a total of 114 interviewed households were under communal ownership of land tunure system. For instance, ninety-four (82.5%) of interviewed households had access to communal land for farming. The sampled households were characterized by smallholdings with land size ranging from 0.5 ha – 2 ha across the villages (Table 3.7). The smallholding land were distributed into two categories such as; homegardens (mean size 0.25±0.2 ha) and outfields (mean sizes 0.89±0.3 ha) (Table 3.7).

**Table 3.7:** Mean distributions of farm sizes as homegardens and outfields across the study locations (n =94)

| **Variable** | **Village** | | | | | |
|---|---|---|---|---|---|---|
| | **1 (n=21)** | **2 (n=18)** | **3 (n=16)** | **4 (n=21)** | **5 (n=18)** | **Overall (N=94)** |
| % response | 22.3 | 19.1 | 17 | 22.3 | 19.1 | 100 |
| Homegarden | 0.28±0.14 | 0.23±0.20 | 0.26±0.17 | 0.24±0.12 | 0.21±0.11 | 0.25±0.2 |
| Outfield | 0.85±0.31 | 0.91±0.31 | 0.85±0.37 | 0.85±0.31 | 0.81±0.17 | 0.85±0.3 |

1 = Lower Hopefield, 2 = Gaga, 3 = Khayamnandi, 4 = Krwakrwa, 5 = Melani

Overall, cropping land sizes ranged from 0.1 ha – 0.9 ha, and 0.5-2 ha, as homegardens and outfields, respectively (Table 3.7). Homegardens across the villages ranged from 0.1 ha - 0.6 ha (0.5±0.14) in Lower Hopefield, 0.1 ha - 0.9 ha (0.8±0.20) in Gaga, 0.1 ha - 0.6 ha (0.5±0.17) in Khayamnandi, 0.1 ha - 0.6 ha (0.5±0.12) in Krwakrwa, and 0.1 ha - 0.4 ha (0.3±0.11) in Melani (Table 3.7).

Households in Gaga had the highest mean outfields size 0.91 ha, followed by Lower Hopefield, Khayamnandi, Krwakrwa, and Melani with 0.852 ha, 0.85 ha, 0.848 ha, and 0.811 ha, respectively (Table 3.7). Homegardens mean sizes across the households followed a decreasing trend: Lower Hopefield (0.281 ha) > Khayamnandi (0.256 ha) > Krwakrwa (0.243 ha) > Gaga 0.228 ha > Melani (0.211 ha) (Table 3.7). Figure 3.2 shows mean size distribution of homegardens and outfields in the study area by gender. The average mean size of homegarden was 0.26 ha for male-headed households and 0.24 ha for female-headed households. Both male and female-headed households had outfield areas larger than 0.5 ha of, 0.97 ha in male-headed and 0.85 ha in female-headed.

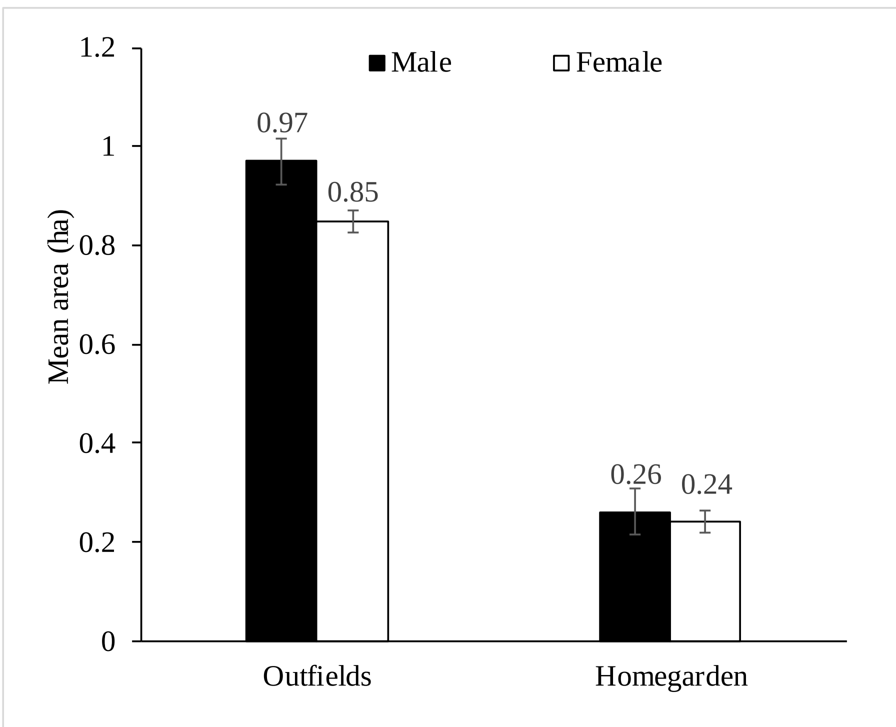


**Figure 3.2:** Mean sizes of homegardens and outfields size (ha) for the 94 households with farmland distributed by gender

*3.3.2.2. Cropping practices in farm land smallholdings*

Furthermore, it could be deduced from the findings of the study that, only fifty-five (48.3%) of the 94 (82.5%) households with farmland smallholdings were growing a range of crops including maize, cabbages, butternuts, potatoes, spinach and pumpkins. Figure 3.3 shows the proportion of crops grown in both homegarden and outfield according to the gender of the farmer.

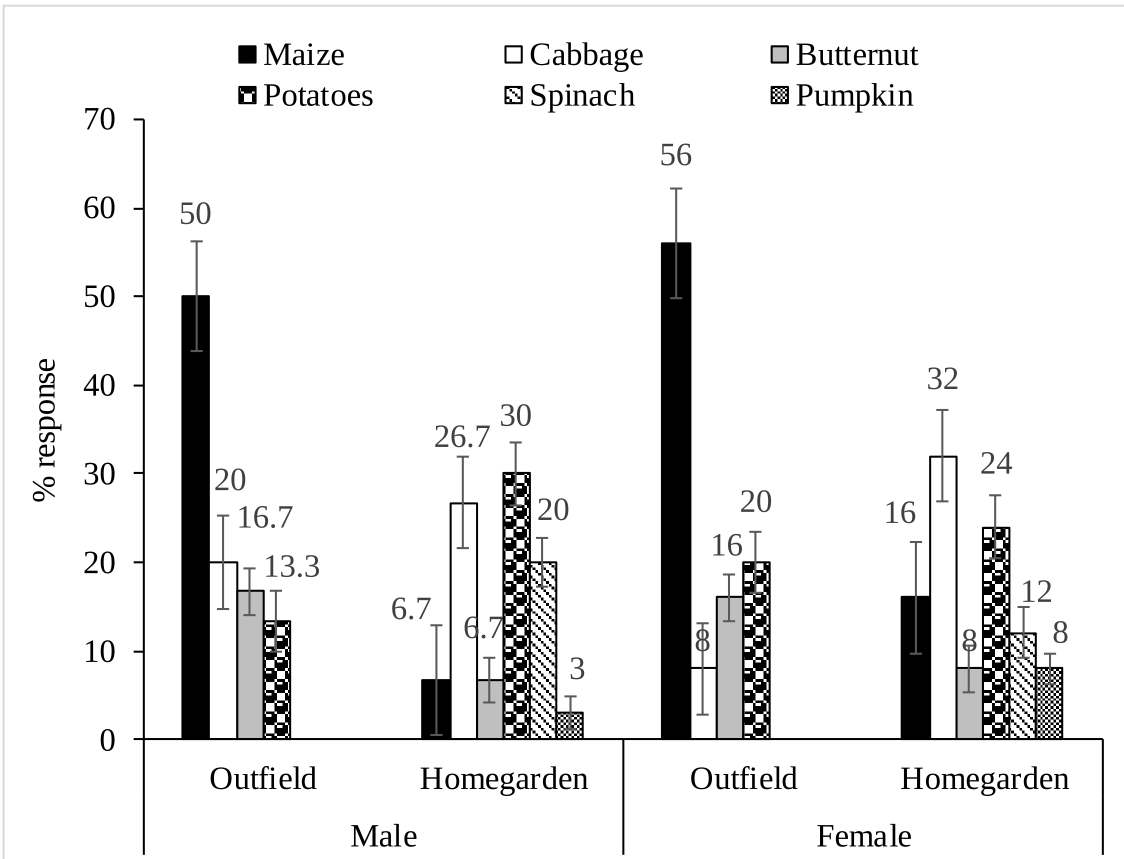


**Figure 3.3:** Proportion responses of crops grown (homegarden and outfield) by gender of the 55 households cropping

Figure 3.4 shows the proportion of responses of crops grown by households in the villages under study. The most common crop that was grown in the outfields was maize as indicated by a higher response proportion of 75% from farmers in Krwakrwa village (Figure 3.4).

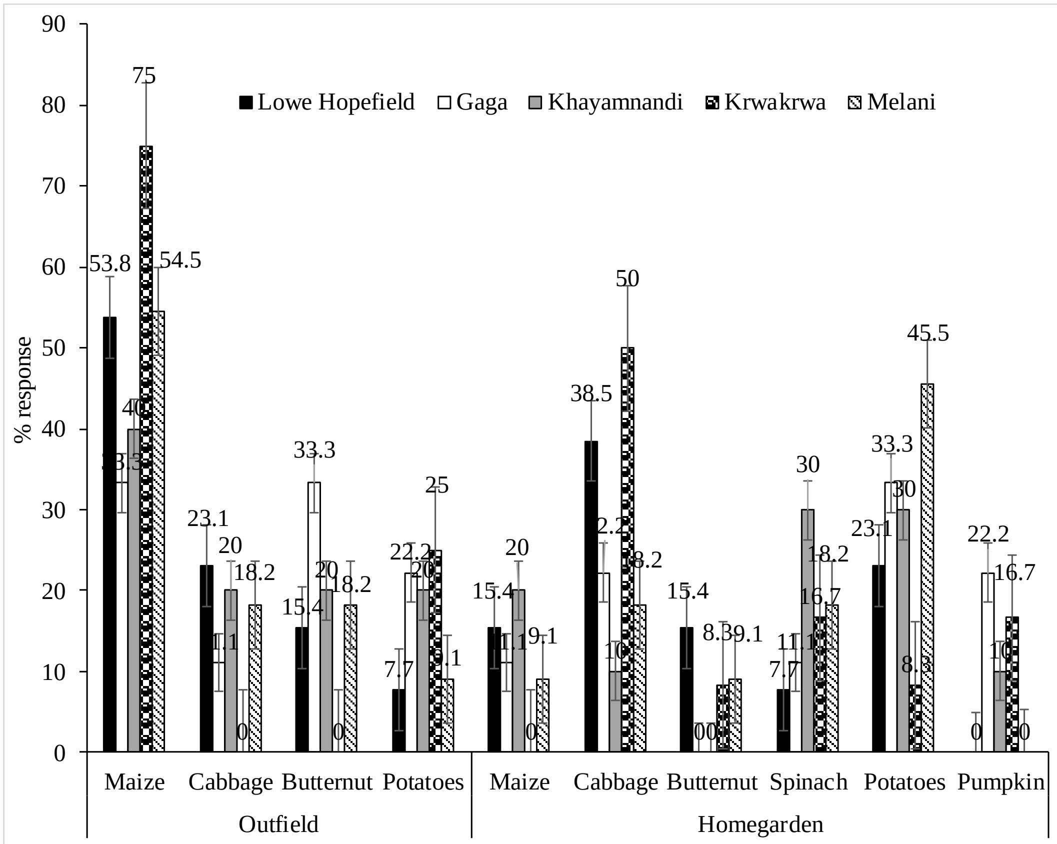


**Figure 3.4:** Responses of crops grown (homegarden and outfield) by village (n= 55)

*3.3.2.3. Household livestock husbandry and categories*

Livestock rearing in this communal system was practiced by all of the 114 interviewed households. Figure 3.5 shows the household livestock numbers distribution in the studied villages of Raymond Mhlaba Municipality.

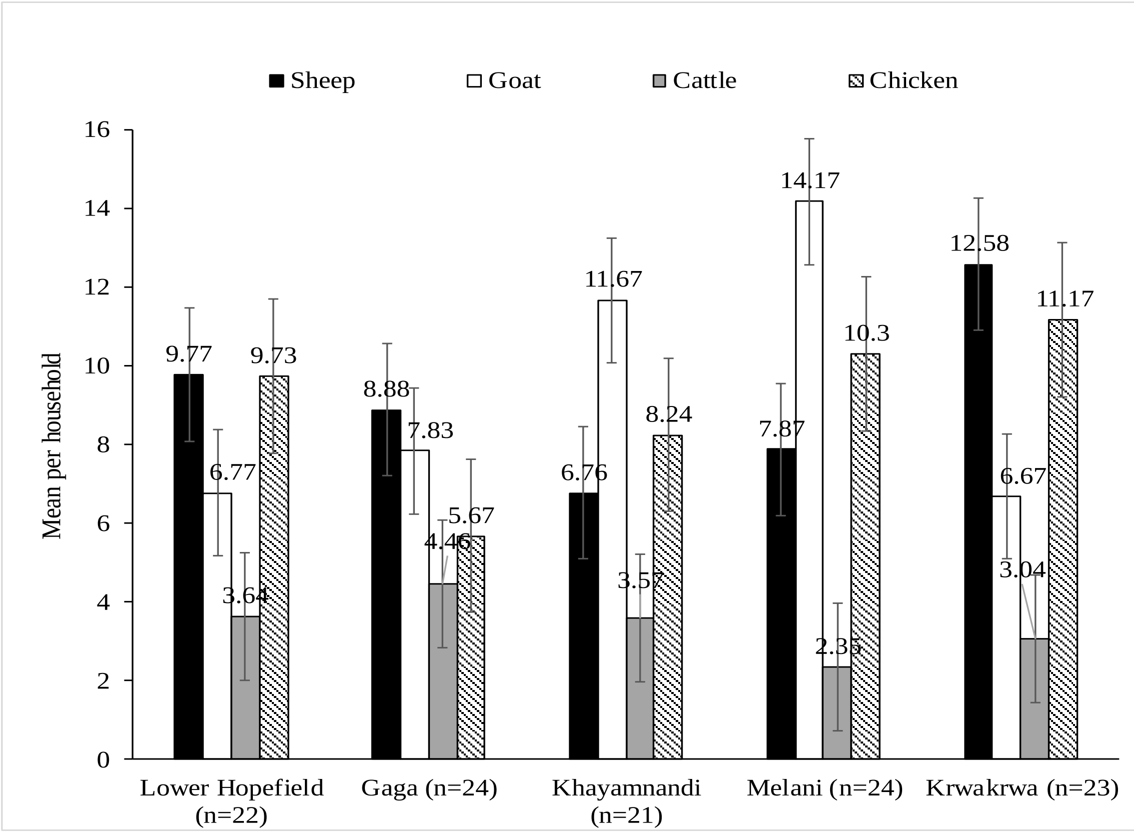


**Figure 3.5:** Household livestock numbers (sheep, goat, cattle and chicken) distribution in the studied villages of Raymond Mhlaba Municipality (n =114)

### 3.3.3. Estimating potential livestock manure production

The quantities of manure available to a household per livestock type per year were also calculated in this study. Table 3.8 shows potential manure production from cattle, goat, chicken and sheep manures.

**Table 3.8:** Potential manure production in kg DM/year from cattle, goat, chicken and sheep numbers for the study sites and households using manure in cropping

| Livestock types | Study population (n=114) | | Household applying manure in cropping (n=40) | |
|---|---|---|---|---|
| | Total manure production (kg DM/year) | Mean household production (kg DM/year) | Total manure production (kg DM/year) | Mean household production (kg DM/year) |
| Cattle | 328210 | 2879±2723.7 | 134996.4 | 3374.9±2549.1 |
| Goat | 93620.88 | 821.2±714.7 | 31294.6 | 782.4±719.1 |
| Chicken | 492.3 | 4.32±4.16 | 177.68 | 4.44±3.31 |
| Sheep | 92305.98 | 809.7±719.9 | 31382.6 | 784.6±788.8 |

Total manure quantities were estimated for households applying manure as fertility amendments (n = 40).

**Table 3.9:** Potential manure production in kg DM/year per household of farmers applying manure as fertility amendments in cropping (n = 40)

| Manure type | **1 (n=24)** | **2 (n=21)** | **3 (n=23)** | **4 (n=24)** | **5 (n=22)** |
|---|---|---|---|---|---|
| **Cattle** | 3468±2249.9 | 5343±2857 | 2531.2±2577.6 | 2531.2±2495.7 | 3468.7±2439.7 |
| **Goat** | 496.7±449.1 | 730.5±588.5 | 989.3±598.2 | 448±488.9 | 1275.9±1031.7 |
| **Sheep** | 876.6±642.7 | 452.9±744.7 | 701.3±945.5 | 1178.5±861.2 | 584.4±737.3 |
| **Chicken** | 2.84±2.13 | 4.08±2.35 | 5.36±4.5 | 3.86±3.1 | 6.16±3.61 |

1 = Lower Hopefield, 2 = Gaga, 3 = Khayamnandi, 4 = Krwakrwa, 5 = Melani

### 3.3.4. Livestock manure utilization for fertility management in cropping

Table 3.11 shows livestock manure utilization and proportions of source livestock manures used. For instance, only 40 (35.1%) of the 55 (48.3%) households growing crops utilized livestock manures for soil fertility management in their fields.

**Table 3.10:** The reason given by household heads for not using manure in cropping (n = 15)

| **Reasons for not using manure** | **Males (n = 6)** | | **Females (n = 9)** | | **Sig** |
|---|---|---|---|---|---|
| | **Frequency** | **%** | **Frequency** | **%** | |
| Lack of interest | 1 | 25 | 3 | 75 | ns |
| Use other soil fertility strategies | 3 | 42.9 | 4 | 57.1 | ns |
| Dirty in handling | 2 | 50 | 2 | 50 | ns |

Significance level (***= p<0.001; **=p=0.01; * = p < 0.05; ns-Not Significant

There was no significant difference (p>0.05) with regards to gender vis-a-vis reasons given for not using manures of the respondents by gender (Table 3.10). The frequency of female household's heads (9) not using manure was higher as compared to male household heads (6). The use of manure use with regard of gender of household head showed that 23 (41.8 %) were males, and 17 (30.9%) were females (Table 3.11).

The majority of the household head indicated that they used goat manure (Table 3.11). There was no significant difference (p>0.05) with regard to gender of the farmers and the source of manure by respondents in Raymond Mhlaba Municipality.

**Table 3.11:** Characteristics of household manure utilization by gender in Raymond Mhlaba Municipality (n = 40)

| Variable | Male | | Female | | Total | | Sig |
|---|---|---|---|---|---|---|---|
| | Freq | % | Freq | % | Freq | % | |
| Manure use | 23 | 41.8 | 17 | 30.9 | 40 | 100 | |
| **Manure source** | | | | | | | |
| Cattle | 5 | 21.7 | 2 | 11.8 | 7 | 17.5 | ns |
| Goat | 11 | 47.8 | 11 | 64.7 | 22 | 55 | ns |
| Sheep | 7 | 30.4 | 4 | 23.5 | 11 | 27.5 | ns |
| **Manure usage** | | | | | | | |
| Homegarden (HG) only | 10 | 43.5 | 11 | 64.7 | 21 | 52.5 | ns |
| Outfields (OF) only | 2 | 8.7 | 2 | 11.8 | 4 | 10 | ns |
| Both HG and OF | 11 | 47.8 | 4 | 23.5 | 15 | 37.5 | ** |
| **Method of application** | | | | | | | |
| Band placing (BP) | 6 | 26.1 | 2 | 11.8 | 8 | 20 | * |
| Broadcasting (BC) | 13 | 56.5 | 9 | 52.9 | 22 | 55 | ns |
| Both BP and BC | 4 | 17.4 | 6 | 35.3 | 10 | 25 | * |

Significance level (***= p<0.001; **=p=0.01; * = p < 0.05; ns-Not Significant

*3.3.4.1. Manure application rates utilized by smallholding farmers*

The emerging results indicated that smallholder farmers applied manure at rates ranging from 500 kg–1200 kg on smallholing farmland between 0.1 ha and 2 ha. On average mean household manure application in the homegardens was amounting to 644±181 kg whereas, in outfields it amounted to 719±182 kg (Table 3.12). There was no significant difference (p>0.05) in the villages under study with respect to gender on manure application either in homegardens and outfields neither, were there any no significant differences (p>0.05) in the villages with respect to gender of the respondents in Raymond Mhlaba Municipality.

**Table 3.12:** Mean manure application quantities (kg) by gender in Raymond Mhlaba Municipality (n = 40)

| Variable | Male | | Female | | Sig |
|---|---|---|---|---|---|
| | Mean | (%) | Mean | (%) | |
| **Smallholding** | | | | | |
| Outfields | 648±177 | | 638±191 | | ns |
| Homegardens | 720±173 | | 718±200 | | ns |
| Total manure use | 1367±221 | 57.5 | 1356±221 | 42.5 | ns |
| **Total village** | | | | | |
| Lower Hopefield | 1488±253 | 10 | 1300±141 | 12.5 | ns |
| Gaga | 1275±275 | 10 | 1350±212 | 5 | ns |
| Khayamnandi | 1425±256 | 15 | 1200 | 2.5 | ns |
| Krwakrwa | 1250±94 | 12.5 | 1263±239 | 10 | ns |
| Melani | 1400±185 | 10 | 1520±261 | 12.5 | ns |

Significance level (***= $p<0.001$; **=p=0.01; * = $p < 0.05$; ns-Not Significant

### 3.3.5. Factors influencing livestock manure utilization in cropping

*3.3.5.1. Factors that influenced farmers' decision to use manure*

Table 3.13 shows a summary of statistics for the binary logistic model used to estimate probabilities of households to adopt manure utilization. The model required six iterations to generate parameter estimates. The likelihood ratio test indicated that the specified model explained significant non-zero variations in the factors influencing household decisions to adopt manure utilization in soil fertility management. The model correctly classified 78.2% of the households that utilized manure. Nagelkerke $R^2$ (0.42) was relatively high for the qualitative response model.

**Table 3.13:** Summary statistics for the binary logistic model

| Statistics | Value |
|---|---|
| Chi-square | 18.67 |
| -2 Log likelihood | 45.78 |
| Cox and Snell R square | 0.29 |
| Nagelkerke R square | 0.42 |
| Percentage of farmers correctly classified | 73.2 |
| Total number of iterations | 6 |

The estimates of likelihood of predictor variables influencing households to use manure for soil fertility management according to the binary logistic model are shown in Table 3.14. Seven predictor variables were analyzed in explaining the farmers' decision to utilize manure. The three factors that significantly influenced household decision to adopt manure use were labour unit 2 (45-59 years) (p=0.04), outfields farm land size (p=0.05), and homegardens farm land size (p=0.02).

**Table 3.14:** Parameter estimates of maximum likelihood for manure utilization according to binary logistic regression (n = 55)

| Variable | (β) | Wald | Significance | (Ex β) |
|---|---|---|---|---|
| Gender | -0.78 | 0.68 | 0.41 | 0.46 |
| Household size | 0.74 | 3.68 | 0.06 | 2.09 |
| Labour unit 1 (18-44 years) | -1.21 | 3.65 | 0.06 | 0.30 |
| Labour unit 2 (45-60 years) | 1.68 | 4.23 | 0.04* | 5.35 |
| Labour unit 3 (>60 years) | 0.41 | 0.22 | 0.64 | 1.51 |
| Outfields farm size | -3.51 | 3.71 | 0.05* | 0.03 |
| Homegardens farm size | -7.70 | 5.38 | 0.02* | 0.00 |
| Constant | 2.58 | 1.38 | 0.24 | 13.23 |

Significant at 5 % *probability level, ns – not significant

*3.3.5.2. Factors influencing quantities of livestock manure utilized by households*

Table 3.15 shows significant ($p \leq 0.01$) effect on quantities of manure applied in the outfields by farm size. Results for one-way ANOVA obtained non-significant ($p \geq 0.05$) effects on quantities of manure applied by the households with regards to gender, household size, labour units and homegarden farm size. The quantities of manure applied by the households were declining with an increase in outfield land size (from 0.5 ha – 0.9 ha), but started increasing as the land size was increasing (from 0.9 ha – 2 ha).

**Table 3.15:** One-way ANOVA for factors influencing quantities of manure applied by the households (n = 40)

| **Variable** | **Effect** | |
|---|---|---|
| | **F statistics** | **Probability (0.05)** |
| Gender | $F_{(14,39)}$ 0.26 | 0.62ns |
| Household size | $F_{(14,39)}$ 1.33 | 0.26ns |
| Labour unit 1 (18-44 years) | $F_{(14,39)}$ 0.28 | 0.89ns |
| Labour unit 2 (45-60 years) | $F_{(14,39)}$ 1.07 | 0.38ns |
| Labour unit 3 (>60 years) | $F_{(14,39)}$ 1.73 | 0.19ns |
| Outfields farm size | $F_{(14,39)}$ 3.61 | 0.007** |
| Homegardens farm size | $F_{(14,39)}$ 0.96 | 0.45ns |

Significance level (***= p<0.001; **=p=0.01; * = p < 0.05; ns-Not Significant

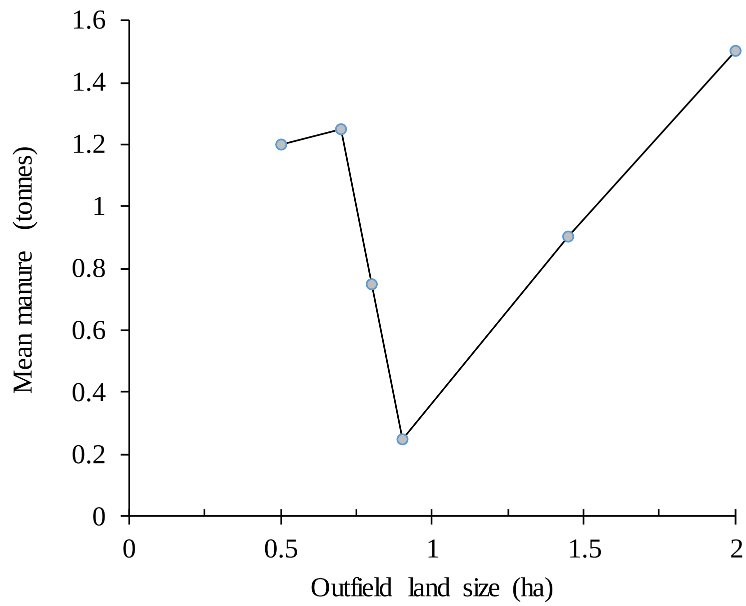


**Figure 3.6:** Mean livestock manure quantities applied at farmers' households with land size for outfield farm sizes

## 3.4. Discussion

### 3.4.1. Household socio-economic demographics

The findings of this survey pointed out that there were more female headed-households. This could be due to high rural to urban migration of males in search for better job opportunities. Similar sentiments were echoed by Hebinck and Monde (2007) who described household farming in the Eastern Cape to be gender sensitive in favour of females. This may imply that, women play a significant role in decision making in farming operations in the rural areas in Raymond Mhlaba Municipality. On the other hand, the same study conducted by Hebinck and Monde (2007) found that most men can partake in decision making pertaining to agriculture regardless of whether they are resident on the farm or not. meanwhile Lahiff (2000) is of the view that , a possible drawback of high female involvement in agriculture could be engagement in manual labour which is quite demanding.

Household family size and age distributions given by head respondents were not significantly different among the households in each of the villages. The inclusion of individuals in the age category of 45-59 and >60 in this study could result in labour shortage. Similar observations were made by Manyevere *et al*. (2014) who found that elderly people between the ages of 55–64 years and >65 years were dominating the household heads in Raymond Mhlaba Municipality. This age range is usually characterized by relocated elderly people to communal areas as retirement plans. The findings of the study further indicated that, the majority of the households age distribution which was characterized by old family members signals a critical gap which may exist in the future prospects in farming activities. This would potentially result in future decline of agricultural activities and knowledge of traditional livestock manure use to supplement chemical fertilizers. The implications of these results are that agricultural training should target younger generations for them to appreciate the benefits and ensure its future continuity.

The general educational status of the household heads showed that 30% of the farmers were not educated. Literacy levels are important in transferring new farming technologies through extension services. Low literacy rates in the Raymond Mhlaba Municipality were associated with high proportions of the old age population (Manyevere *et al*., 2014). These findings were expected based on the assumption that the Eastern Cape is characterized by lower adult proportion of literacy (72.3%) as compared to the Western Cape (94.6%) (Statistics South Africa, 2017).

Sheep sales were considered to be the most dominant income source contrary to the findings by Bester *et al*. (2009) and Rumosa-Gwaze (2009) where sales from livestock was minimal. This could be due to village selection used in this study which focused on households that practiced both livestock and crop production. The findings justify the need for exploring farming systems to demarcate their productivity in relation to the extent of cropping and livestock.

### 3.4.2. Characteristics of smallholder farming system

Smallholder farming system in this study was typical to that reported by van Averbeke *et al*. (2008) involving a mixture of small and large livestock husbandry, subsistence maize cropping and selected vegetable farming. Households considered livestock rearing as a major agricultural practice and a critical factor to the economic value in their livelihoods. The distribution of livestock numbers per household was not normally distributed and instances of certain households owning large and small livestock holdings were observed in the present study. The findings are in consonance with a study conducted by van Averbeke *et al*. (2008). For instance, local tradition views about ownership of goats and sheep is associated with success (van Averbeke and Bennett, 2007). This study found that livestock provided income and this could be the reason why an expansion in production was observed. Bester *et al*.

(2009) and Masika and Mafu (2004) obtained results that are consistent with the findings of the present study where the main reasons for household livestock rearing was for economic value and cultural reasons.

Findings from the present study revealed that arable land utilization for cropping was low. Emerging results are in consistence with previous studies in the central EC which mentioned crop production to be limited by water deficits, and low soil fertility (van Averbeke and Bennett, 2007). The finding that 82.5% of the households were endowed with arable smallholdings ranging from 0.5 ha – 2 ha aligns with previous studies in the Eastern Cape by van Averberke *et al*. (2008), Manyevere *et al*. (2014), Muzangwa *et al*. (2017). In addition, Manyevere *et al*. (2014) reported that more than 70% of these arable smallholdings are left uncultivated and only a third of such land is cultivated in seldom times. This is in consistence with findings from the present study where only 58.5% of the households were currently involved in cropping. Manyevere *et al*. (2014) futher associated the lack of farmers interest in cropping to soil infertility and labour shortages. The present study also found that the most grown crops were maize in the outfields, as well as cabbages and spinach in the homegardens. Crop production under smallholder farming system is mainly for subsistence consumption and where there are surpluses, crops are sold to provide income (Hebinck and Monde, 2007; van Averbeke *et al*., 2008). The findings of the study justify the need to address farmers' crop production constraints such as low soil fertility so as to improve crop yields and sustain their livelihoods.

The findings of the study further revealed that, greater diversity of crops are grown by the households in the homegardens than in the outfields. This could be due to limited resources such as seeds, fertilizes, farming equipment and limited labour availability which favors cropping in homegardens more than  in outfields. Van Averbeke *et al*. (2008) corroborates that crop production in the garden suits the resources available to the smallholder farmers. Smallholder farmers are more motivated in cropping on small pieces of land which they can view as manageable hence, the diversity in crop types obtained from the results of the study.

### 3.4.3. Potential livestock manure production quantities

The observed dry livestock manure quantity estimated for the present study reflected the richness of livestock production in the Eastern Cape Province. The results corroborate with findings of previous studies conducted by Masika and Mafu (2004), Bester *et al*. (2009), and Rumosa-Gwaze (2009) who obtained high goat and sheep numbers in the same province. Livestock type and numbers as well as, other factors namely: management system, feed quality, amount and extent of grazing regime influence the quantity of livestock manure available to EC smallholder farmers' households (Yoganathan *et al*., 1998; Mkile, 2001). Management system of livestock production in the EC smallholder farming is pen rearing or kraaling at night and is associated with free range grazing during the day (van Averbeke *et al*., 2008). This allows for manure accumulation and easy access from the kraals (Yoganathan *et al*., 1998). Dry manure production per TLU per year in this current study was found high in cattle. The high quantities of manure production in the semi-arid areas of EC Province has been corroborated by previous studies estimated manure production to be 1.6 Mt $year^{-1}$ (Mkile, 2001).

### 3.4.4. Livestock manure use by smallholder farmers

Livestock rearing is the dominant agricultural practice in the central EC (van Averbeke and Bennet, 2007). The mixed farming system is dominated by livestock rearing  as compared to crop production (van Averbeke and Bennet, 2007). Livestock manure is a valuable plant nutrient source with potential to meet the N, P, K and Ca fertilizer requirements in South Africa (Mkhabela and Materechera, 2003). However findings of this study showed that 40 out of 55 cropping households were applying livestock manures for soil fertility management. This is consistent with the findings by Mkile (2001) and Muhereza *et al*. (2014) who established that livestock manure is widely used by smallholder farmers to improve soil fertility and crop yields. Furthermore, it could be deduced from the results,  that farmers who were not using livestock manures reported the use of other soil fertility strategies. This could result in the abandonment of manure utilization since the South African government provides support black farmers through supply of hybrid seeds and chemical fertilizers. The results of the study signified a high potential for manure accumulation in the EC.

Meanwhile, the results from the collected data showed that, currently livestock manure was being applied by 57.5% males and 42.5% female farmers in the studied villages of the Raymond Mhlaba Municipality with minimal knowledge of their nutrient status. Hence, the nutrients required for optimal crop growth may be insufficient. Goat manure was the most commonly used type of livestock manure and was broadcasted in the homegardens. The findings of the study imply that manure rates used by the farmers in homegardens were higher as compared to the outfields in comparison with the areas applied. This is in agreement with a study by van Averbeke *et al*. (2008) who obtained frequent broadcasting of manures in the nearby homegardens of smallholder farmers. Mandiringana *et al*. (2005) also conducted a soil fertility survey of communal crop fields and found that garden soils have higher soil fertility as compared to the surrounding outfields. This aligns with the findinds of the current study.

This study showed that manure quantities utilized by farmers in farmland have improved. A previous study conducted by Yoganathan *et al*., (1998) in the central EC showed that kraal manure application in fields ranged from 3 to 1820 kg $ha^{-1}$. The application rates obtained by this study are not different to those previously obtained by Yoganathan *et al*. (1998) and indicates the rate of kraal munure applicaton by farmers is still minimum. The same study by Yoganathan *et al*. (1998) recommended application rate of 20 t $ha^{-1}$ for optimum cabbage production indicating farmers are reluctant in the utilization of kraal manure as a fertilizer resource.

### 3.4.5. Household factors influencing manure use by smallholder farmers

This study further identified factors that influence farmers' decisions in the use of cattle, goat and sheep manure for managing soil fertility. Significant factors obtained by binary logistic regression model explained their probabilities and significance in farmer's decision to adopt manure use for soil fertility management. These results are in consonance with studies by Mkhabela and Materechera (2003) and Waithaka *et al*. (2007) who predicted factors like farm size and household labour (size) to significantly influence the adoption of manure use by smallholder farmers.

In addition, the findings of this study showed that household size, age between 45-59 years, homegarden size, and outfield size were the most prominent predictor variables which influenced the adoption of manure use. The more the number of people in the 45-59 age group the higher the likelihood of adopting manure use. This could be due to the fact that, more household labour would be available. Similarly, 45-59 age group increased the likelihood of the household to adopt manure use. These results are consistent with findings by Waithaka *et al*. (2007) who found that the household age group influenced manure quantities applied by farmers and concluded that household labour is a factor that determines manure adoption.

Findings of the study also showed that manure use was also significantly influenced by the size of household homegardens or outfields. This would imply that, as the size of farm increases  the farmers' interest in manure use was declining. This likelihood showed that a farmer was more likely to use manure in the homegarden than in the outfields for soil fertility management. These result echo the findings of van Averbeke *et al.* (2008) who mentioned that smallholder farmers tend to focus of small pieces of land when applying manure. Also, Mkhabela and Materechera (2003) found that manure use declined as farm size increased, and this could best explain the findings of the study.

### 3.5. Conclusions and recommendations

Demographic factors such as high female ratio and low educational levels of the household heads requires government intervention that encourages males to gain interest in agriculture. The results showed that, all the farmers kept at least one type of livestock per household, but only a small proportion. Farmers grew crops such as maize, cabbage, spinach and potatoes, and maize was the most commonly crop grown by all the farmers cropping. Availability of manure would be in limited quantities in the Raymond Mhlaba Municipality if all the farmers were to utilize manure in cropping at recommended application rates. Only a small proportion of cropping farmers utilized manure for soil fertility management and applied higher quantities in homegardens than in the outfields.

# 4. CHARACTERISTICS OF BIOCHAR PRODUCED FROM SLOW PYROLYSIS OF LIVESTOCK MANURES FOR AGRONOMIC APPLICATION


## Abstract

Biochar production from livestock manures is gaining popularity for soil application because of its ameliorative effects on soil quality, reducing mineral fertilizer consumption, and sequestrating carbon. It is generally accepted that pyrolysis of manures results in biochars of agronomic nutritional value. However, the nutritional composition of the biochar is highly determined by the manure type and source. This study was carried out to investigate the chemical and physical properties of biochar produced from slow pyrolysis of cattle, goat, sheep and poultry manures using the two drum retort method. Pyrolyzed and unpyrolysed manure samples were characterized for pH, electrical conductivity, ash content, C/N ratio, total elements (C, N, P, K, Ca, Mg), and metal elements (Na, Zn, Cu, Mn, Fe, Al). Biochars physical properties including bulk density, SEM images and water holding capacity were also determined. The results show that drum retort method of slow pyrolysis for cattle, goat, sheep and poultry manures at a temperature of 400 $^{o}$C was able to convert the manures into biochar within the duration of 3 hours. The yield of the biochars produced from cattle, goat, sheep and poultry manures were 63%, 72%, 61% and 83% on a weight basis. A one-way analysis of variance was used to compare the pH, electrical conductivity, nutrient content, carbon content, proximate analysis and metal concentration properties of the manures with the resulting biochars. The results showed that the properties of the biochars were significantly ($p \leq 0.05$) higher from that of the manures. The pH of the manures was increased in the biochars and were in the following order: sheep manure biochar (9.19)> cattle manure biochar (9.12)> goat manure biochar (9.09)> poultry manure biochar (8.75). The ash contents of the biochars were 42%, 58%, 42%, and 44% for cattle, goat, sheep and poultry, respectively. The electrical conductivities were not correlated with ash content. The Ca and K rich, poultry manure biochar (13.8%) and sheep manure biochar (6.6%), resulted in the highest EC, sheep manure biochar (8.1 mS cm$^{-1}$) and poultry manure biochar (9.2 mS cm$^{-1}$). The biochars contained substantial amounts of plant nutrients. Scanning electron micrographs (SEM) analysis showed that, the biochars had porous structures ranging from 1.23um to 5.23um which are very important for water conductance and holding capacity. The water holding capacities of cattle, goat, sheep and poultry biochars were 141%, 151%, 160%, and 180%, respectively. The bulk densities were 0.91 g kg$^{-1}$, 0.89 g kg$^{-1}$, 0.94 g kg$^{-1}$and 0.75 g kg$^{-1}$ for cattle, goat, sheep and poultry manure biochars. Generally, pyrolysis of these manures resulted in the concentration of mineral elements in the biochars. In conclusion, poultry manure resulted in the highest biochar yield. Whereas, goat and sheep manure biochars had agronomic properties more suitable for fertility remediation than cattle manure biochar. Therefore, goat and sheep manure biochar proved to be highly concentrated in mineral elements and had high pore structures, while poultry manure biochar was a suitable option for C sequestration.

*Keywords*: Biochar, agronomic properties, livestock manure, slow pyrolysis

## 4.1. Introduction

Manure production in large quantities tends to have an environmental threat if not properly managed (Zhuang and Li, 2017). Livestock kraal manure has potential to replace chemical fertilizer requirements (Mnkeni and Mkile, 2006). However, with requirements to increase food production, the use of organic fertilizers has increased and manure nutrients are not always used to their potential. In attempts to improve the fertilizer value of livestock manures, composting through vermicomposting was shown to improve nutrient availability of manures (Mupondi, 2010). However, due to rapid mineralization associated with fresh organic amendments, other options such as biochar are being advocated for (Calderon *et al*., 2015).

The Eastern Cape (EC) Province is dominated by smallholder mixed farming systems as shown in Chapter 3. There is also a high preference for livestock rearing than crop cultivation in this system (Mkile, 2001). Dry manure production in the EC was estimated at 1.6 Mt $year^{-1}$ (Mkile, 2001) and as such, manure could be an important feedstock in biochar production (Klass, 1998). The term biochar is used for the resultant charcoal material from which organic matter was carbonized. Gomez *et al*. (2014) described it as a black aromatic carbon rich material. According to Lehmann *et al*. (2009), on average a ton of dry feedstock can create 400kg of biochar containing 80 to 90% pure carbon at 300 to 700 $^oC$, under low oxygen conditions.

The choice of method in biochar production and its characterization are very important steps in determining its application (Cantrell *et al*., 2007; Cantrell *et al*., 2012). In fast pyrolysis, biomass is heated very rapidly (up to 1000°C $sec^{-1}$) in the absence of oxygen and favors more output of bio-oil and gaseous products at the cost of biochar (Brewer *et al*., 2011). Slow pyrolysis conditions have slow heating rates (1-20°C $min^{-1}$) and result in higher char outputs suitable for agricultural production (Spokas *et al*., 2011). Thus, instead of applying fresh organic materials, alternative conversion of biomass to biochar has received significant attention as a strategy to minimize rapid mineralization, sequester soil carbon and mitigate climate change (Alburquerque *et al*., 2014; Schulze and Glaser, 2012; Sohi *et al*., 2009). However, due to their nature, biochars vary in their chemical and physical properties. Thus, due to these variations biochars must undergo characterization for the determination of their properties.

Livestock manures have been used for biochar production in other countries. Biochar produced from goat manure in Taiwan was found to be rich in nutrients (N, P, K, Ca, and Mg) and important for soil fertility improvement (Touray *et al*., 2014). In Japan, biochar is produced from cattle manure (Uzoma *et al*., 2011). Studies done in Australia and America also produced biochar form poultry manure (Chan *et al*., 2008, Revell *et al*., 2012). The biochar produced from manure-based feedstocks were reported to have significant fertilizer value due to the concentration of nutrient elements. Initial feedstock properties have been shown to determine the biochar properties (Enders *et al*., 2012). Zhao *et al*. (2013) showed that both feedstock properties and production conditions affected the yield and properties of biochar. However, studies with biochars produced from livestock manures as feedstock are lacking in South Africa.

Acoording to Ronsse *et al*. (2013) slow pyrolysis of wood, wheat straw, green waste and dried algae feedstock at 300, 450, 600 and 750$^{o}$C had no significant effects on chemical properties, but significant differences were obtained due to feedstock properties In addition, Touray *et al*. (2014) conducted similar pyrolysis experiments with only one feedstock, goat manure at five temperatures (400, 500, 600, 700, and 800$^{o}$C) and produced biochars with competitive agronomic properties. They concluded that, at temperatures of 800$^{o}$C the biochars had proximal, physical, and chemical properties suitable for agronomic application. Thus, biochar must undergo characterization so as to provide recommendations for their agronomic utilization. The main objective of the study was to produce and characterize biochar from livestock manures (cattle, goat, sheep and poultry) using slow pyrolysis method.

The specific objectives were to;

i. Compare the chemical properties of cattle, goat, sheep and poultry manures with their resultant biochars.
ii. Compare the proximal, and physical properties of the biochars produced from cattle, goat, sheep and poultry manures.

The null hypotheses were;

i. The chemical properties of cattle, goat, sheep and poultry manures are not different from their resultant biochars.
ii. There is no difference in the proximal and physical properties of the biochars produced from cattle, goat, sheep and poultry manures.

## 4.2. Materials and methods

### 4.2.1. Manure resources and preparation

Samples of manure were collected from local communal farmers within the vicinity of University of Fort Hare, Alice. Sheep manure was collected in Khayamnandi village, cattle manure in Ntselamanzi village, goat manure was collected from Gaga village, and poultry bedding manure from Fort Cox Agricultural College. Livestock kraal manures from cattle, sheep and goat were collected in kraals at the top surface. Poultry manure was collected from broiler chickens which was a mixture of broiler litter and pine bark dust. All the samples were transported to and air dried at the University of Fort Hare, Agronomy shade in preparation for processing. The air dried sub-samples were ground to 2 mm for chemical and proximate characterization, while the remaining manure samples were crushed to small fragments in preparation for pyrolysis. The prepared biochar materials were ground and sieved through 0.25 mm square mesh sieve.

### 4.2.2. Slow pyrolysis tests

Figure 4.1 shows a representation of the nested drum retort (two-drum) used for slow pyrolysis. The biochar production processes were conducted at the University of Fort Hare research farm, located in Alice, Eastern Cape Province (32°46´ S and 26°50´E). The retort was made of steel cylindrical (drums) containers consisting of the fuel (large drum) and carbonization (small drum) chamber. The large drum (fuel chamber) measured 0.57 m × 0.90 m (diameter × height; approximate volume of 200 litres) with perforations on the sides for oxygen supply to burning fuel. The smaller drum (carbonization chamber) measured 0.31 m × 0.40 m (approximately 20 litre volume), air-tightly closed and placed inside the bigger drum.

In each test, 1 kg of sample was heated from atmospheric to 400$^{o}$C and maintained for at least 3 hours to allow sufficient time for pyrolysis. A pyrolysis temperature of 400$^{o}$C was selected as an indicative temperature for comparison of biochar characteristics. Thermocouples (*k* type) were installed to monitor temperatures in each process. Production processes were carried out in triplicates for each manure type and the times for the processes were timed using a stop watch. The only product of interest in this process was biochar.

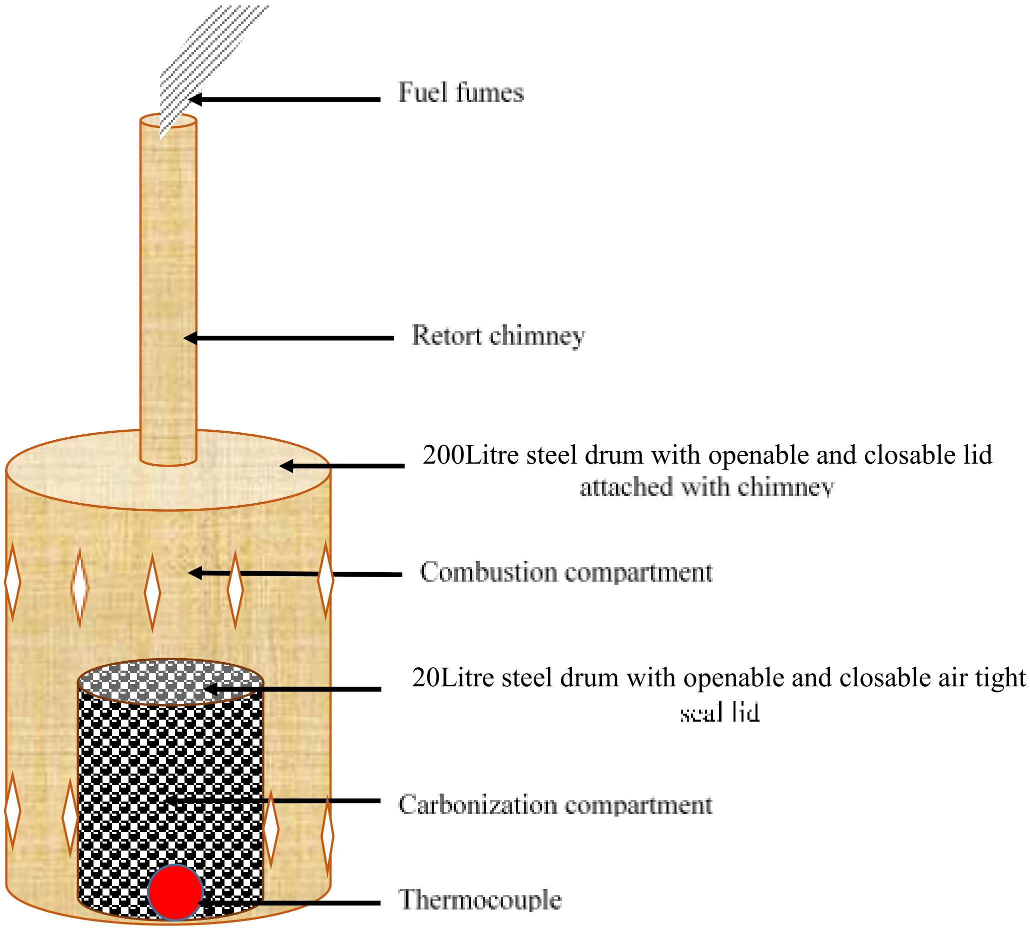


**Figure 4.1:** Representation of the slow pyrolysis retort

### 4.2.3. Manure and biochar characterization

The elemental composition of manure and biochar samples were analyzed by an independent accredited laboratory, the Soil Fertility and Analytical Services under the Department of Agriculture, Fisheries and Forestry in South Africa, employing the standard methods outlined by the Agri laboratory Association of Southern Africa – Soil Handbook (AgriLASA, 2004). Properties included total (C, N, P, K, Mg, Ca) elements and extractable metal concentrations for Na, Zn, Cu, Mn, Fe and Al. The proximate analysis of biochar samples was based on the ASTM standards (moisture content: ASTM D2867-09, ash: ASTM D2866-11, volatile matter: ASTM D5832-98 and fixed carbon was calculated by difference.

Biochar pH was determined using a pH meter (Crison Instruments, Spain) in a 1:5 (w/v) biochar: deionized water suspension without temperature adjustments to form a homogenous suspension, and the pH was determined after 1 hour of equilibration. This ratio was used because in literature biochar/deionized water suspensions used vary from 1:5 to 1:20 (Singh *et al*., 2010; Wu *et al*., 2011). Electrical conductivity readings were also taken using a conductivity meter (Crison Instruments, Spain) on the same suspension used for pH readings. The bulk density of the biochars was determined following methods used by Stella Mary *et al*. (2016) and water holding capacity was determined following method described by Yargicoglu *et al*. (2014). All analyses were conducted in triplicate. The scanning electron microscope (SEM) images of the biochars were determined in the Botany Department, University of Fort Hare to examine the structural differences (JSM-6390LV, Japan).

**4.2.4. Data analysis**

A one-way analysis of variance (ANOVA) on pH, electrical conductivity, total elements (C, N, P, K, Ca, Mg), and metal elements (Na, Zn, Cu, Mn, Fe, Al) was performed using the JMP statistical software version 13.1 (SAS Institute Inc. 2017). Tukey's least significance differences (HSD) at probability level of 0.05 was used for means separations and were represented with standard deviations. Bivariate correlations (Pearson, two-tailed) were computed to analyze relationships.

## 4.3. Results

### 4.3.1. Biochar yield and proximate analysis

The yield of the produced biochars from cattle, goat, sheep and poultry kraal manures were 63%, 72%, 61% and 83% on a weight basis, respectively (Figure 4.2). The livestock manure biochars had moisture contents ranging from 1.91% to 2.14%. Poultry manure biochar had the highest moisture 2.14 (Figure 4.3a). Figure 4.3c showed that poultry manure biochar had the highest ash. Livestock manures volatile matter (VM) followed this trend; poultry manure biochar 29%, cattle manure biochar 25%, goat manure biochar 27%, and sheep manure biochar 25%. Biochar samples from goat manure and from sheep manure  were (44%) and 47%  and these had the lowest ash proportions, as illustrated in (Figure 4.3b). The results showed that the fixed carbon (FC) cattle manure biochar had 30%,  while, goat manure biochar  was 27%, sheep manure biochar 28% and 21% in poultry manure biochar (Fig 4.3d).

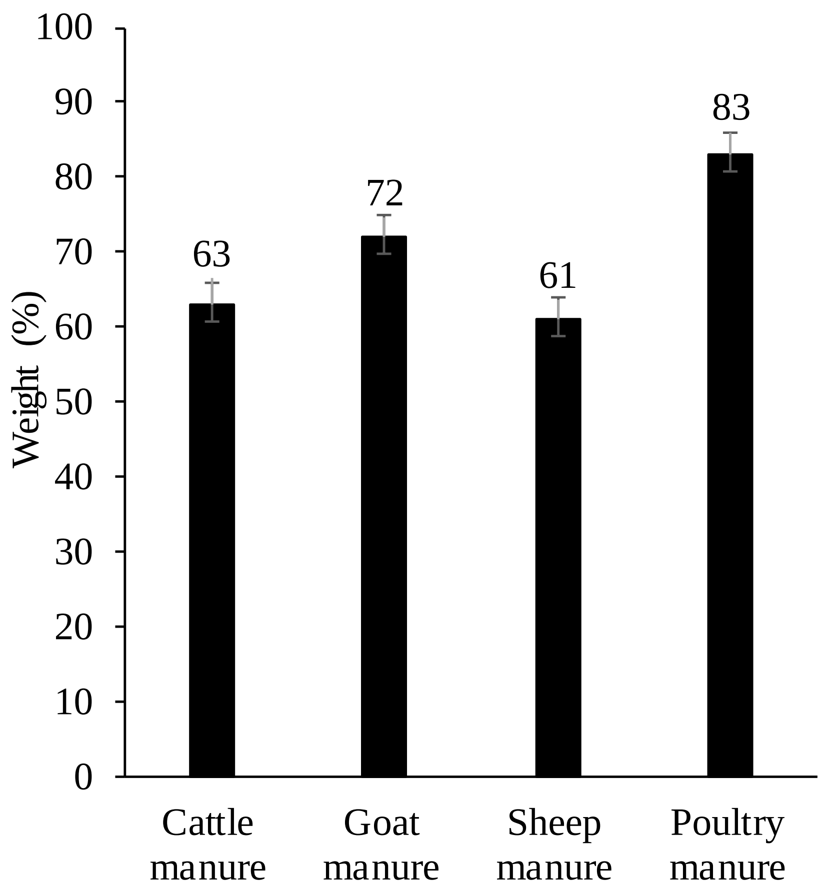


**Figure 4.2:** Biochar yields prepared from livestock manures using slow pyrolysis at 400$^{o}$C

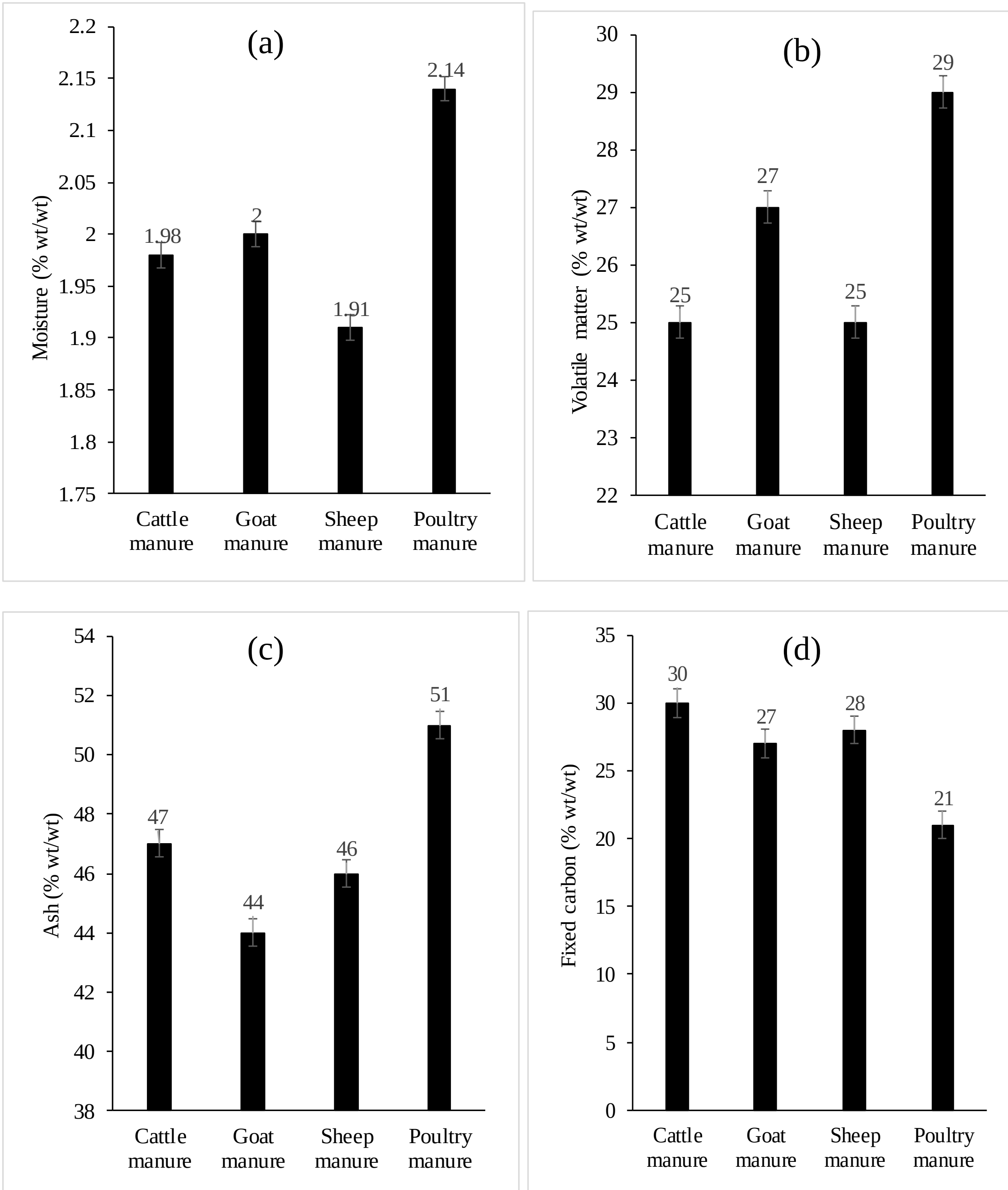


**Figure 4.3:** Comparisons of (a) Moisture, (b) volatile, (c) ash, (d) fixed carbon of livestock manures biochar produced with slow pyrolysis at 400$^{o}$C

### 4.3.2. Biochars pH and electrical conductivity

Table 4.1 shows the comparison of the various livestock manures and their corresponding biochar samples with respect to pH, electrical conductivity, ash content and C/N ratio. Changes in pH and electrical conductivity varied with manure type and were significantly ($p \leq 0.05$) increased in the resulting biochar samples. The pH values of the livestock manures ranged from 7.48 (poultry) to 8.77 (sheep), and the pH of biochar samples varied from 8.75 (poultry) to 9.19 (sheep). In general, biochar pH increases were as follows: cattle manure > poultry manure > goat manure > sheep manure, and were increased by 1.19 > 1.27 > 1.07 > 0.42 units relative to the manures.

**Table 4.1:** Comparison of livestock manures and their biochars with respect to pH, electrical conductivity, and C/N ratio

| Treatments | pH | | EC | |
|---|---|---|---|---|
| | **Feedstock** | **Biochar** | **Feedstock** | **Biochar** |
| Cattle | 7.93±0.21bc | 9.12±0.3a | 5.7±0.3e | 7.4±0.3cd |
| Goat | 8.02±0.1b | 9.09±0.1a | 7.3±0.2d | 7.9±0.3bc |
| Sheep | 8.77±0.1a | 9.19±0.2a | 7.5±0.4bcd | 8.1±0.2b |
| Poultry | 7.48±0.4c | 8.75±0.5a | 6.1±0.2e | 9.2±0.5a |

Each value is the mean of three replicates with the standard deviation and values marked with the same letters in each column are not significantly different ($P > 0.05$).

All biochar samples obtained showed alkaline pH values. Electrical conductivities of the various livestock manures significantly ($p \leq 0.05$) increased in correspondence to their biochar samples. Table 4.1 also highlights that, unit (mS $cm^{-1}$) increased in electrical conductivity for the manures and the corresponding biochar samples relative to the manures followed the following order: poultry manure by (3.1 mS $cm^{-1}$), cattle manure (1.7 mS $cm^{-1}$), and goat and sheep manure (0.6 mS $cm^{-1}$) (Table 4.1).

### 4.3.3. Nutrient characteristics

The total C, N, P, K, Ca, and Mg concentrations of the livestock manures and their respective biochars varied greatly ($p \leq 0.001$) and mainly depended on the manure type (Table 4.2). Poultry manure showed an increase in C value after pyrolysis, sheep manure showed no change while,  cattle and goat manures showed decreases in C value after pyrolysis (Table 4.2). Nitrogen concentration was reduced by more than half in all the livestock manures. Sheep manure TN value of 2.6% was reduced to 1.4%, goat manure from 2.5% to 1.4%, cattle manure was at 2.3% to 1.2%, and poultry manure  reduced from 2.2% to 1.1% in their respective biochars, showing volatilization. All other nutrients showed enrichment with pyrolysis.

Table 4.3 illustrates that  Zn, Cu and Mn heavy metals concentration were significantly ($p \leq 0.001$) decreased following pyrolysis . The concentration of Zn (g $kg^{-1}$) in the livestock manures was as follows: sheep manure 4.1 (g $kg^{-1}$), poultry manure 2.9 (g $kg^{-1}$), goat manure 2.5 (g $kg^{-1}$), and cattle manure 1.9 (g $kg^{-1}$). The decrease in Zn concentration for the subsequent livestock manures was, 0.95 (g $kg^{-1}$) for poultry manure, 0.23 (g $kg^{-1}$) for goat manure, 0.21 (g $kg^{-1}$) for sheep manure, and 0.18 (g $kg^{-1}$) for cattle manure.

**Table 4.2:** Comparison of livestock manures and their biochars with respect to total C, total N, total K, total Ca and total Mg

| Treatments | | | | | | |
|---|---|---|---|---|---|---|
| | **Feedstock material** | | | | | |
| | Total C | Total N | Total P | Total K | Total Ca | Total Mg |
| | ---------------------------------------------------------------%------------------------------------------------------------------- | | | | | |
| Cattle | 30±0.3ab | 2.3±0.2ab | 0.6±0.04d | 2.1±0.1f | 1.6±0.3f | 0.7±0.07e |
| Goat | 29±0.5ab | 2.5±0.2ab | 0.8±0.09d | 3.2±0.1e | 2.7±0.3e | 1.0±0.07d |
| Sheep | 29±1.7ab | 2.6±0.1a | 0.8±0.03d | 4.4±0.2c | 5.5±0.3d | 1.2±0.1c |
| Poultry | 29±3.0ab | 2.2±0.1b | 1.6±0.15b | 3.1±0.08e | 10.7±0.4b | 1.1±0.08cd |
| | **Biochar after pyrolysis** | | | | | |
| | Total C | Total N | Total P | Total K | Total Ca | Total Mg |
| | ---------------------------------------------------------------%------------------------------------------------------------------- | | | | | |
| Cattle | 27±3.2b | 1.2±0.2cd | 0.8±0.04d | 3.8±0.3d | 2.2±0.2ef | 1.0±0.06d |
| Goat | 28±1.4b | 1.4±0.2c | 1.4±0.12c | 6.1±0.1b | 8.3±0.06c | 2.2±0.2a |
| Sheep | 29±1.5b | 1.4±0.2c | 1.1±0.23c | 6.6±0.1a | 8.3±0.4c | 1.7±0.2b |
| Poultry | 32±2.2a | 1.1±0.2d | 3.07±0.14a | 4.6±0.5c | 13.8±1.5a | 1.8±0.1b |

Each value is the mean of three replicates with the standard deviation and values marked with the same letters in each column are not significantly different (p >0.05).

Sheep manure had the highest Cu concentration of 4.1 (g $kg^{-1}$), whilst cattle manure 1.9 (g $kg^{-1}$) had the lowest Cu concentrations. After pyrolysis, cattle manure biochar maintained the lowest Cu concentration at 0.035 (g $kg^{-1}$), whilst poultry manure biochar had the highest level of Cu concentration at 0.14 (g $kg^{-1}$). Surprisingly, Fe and Al concentrations in the livestock manures were increased in the biochars after pyrolysis (Table 4.3).

The results of this study showed that the order of concentration of an individual nutrient components varied amongst the livestock manures. Using N as an example, the concentration from greatest to least for the manures were, sheep manure > goat manure > cattle manure > poultry manure. After pyrolysis, an almost similar trend was obtained in the biochars were cattle manure biochar occupied a third position and poultry manure biochar had the last position. However, with N, the concentrations were reduced with pyrolysis.

Concentrations of total P, K, Ca, and Mg in the livestock manure feedstocks were increased in the biochars with pyrolysis. When compared to the feedstock the concentrations of P, K, Ca, and Mg enrichment in the livestock manure biochars were found mostly in goat and poultry manures. Goat manure biochar was the most concentrated with Ca, Mg and K mineral elements.

#### 4.3.4. Physical characteristics

The bulk density of the biochars differed according to the manure used. Sheep manure biochar had the highest bulk density value 0.94 g $cm^{-3}$, followed by cattle manure biochar

0.91 g $cm^{-3}$, goat manure biochar 0.89 g $cm^{-3}$, and poultry manure biochar 0.75 g $cm^{-3}$ (Table 4.4).

**Table 4.3:** Comparison of selected physical characteristics of biochars produced from livestock manures

| Parameter | Cattle manure biochar | Goat manure biochar | Sheep manure biochar | Poultry manure biochar |
|---|---|---|---|---|
| Bulk density (0.94 g $cm^{-3}$) | 0.91 | 0.89 | 0.94 | 0.75 |
| Water holding capacity (%) | 141 | 151 | 160 | 180 |

**Table 4.4:** Comparison of livestock manures and their biochars with respect to Na, Zn, Cu, Mn, Fe and Al

| Treatments | Na | Zn | Cu | Mn | Fe | Al |
|---|---|---|---|---|---|---|
| | **Feedstock material** | | | | | |
| | ---g/kg--- | | | | | |
| Cattle | 1.9±0.01h | 0.19±0.01de | 0.02±0.00e | 0.47±0.005g | 7.43±0.05b | 5.13±0.009h |
| Goat | 2.5±0.03g | 0.19±0.03de | 0.02±0.03e | 0.42±0.004f | 5.67±0.03c | 3.82±0.03g |
| Sheep | 4.1±0.01d | 0.19±0.01de | 0.03±0.01d | 0.54±0.005e | 3.90±0.05d | 3.24±0.04d |
| Poultry | 2.9±0.06f | 0.58±0.06b | 0.07±0.06b | 0.63±0.008d | 2.05±0.05g | 1.07±0.03f |
| | **Biochar after pyrolysis** | | | | | |
| | Na | Zn | Cu | Mn | Fe | Al |
| | ---g/kg--- | | | | | |
| Cattle | 3.9±0.001e | 0.18±0.003f | 0.033±0.01d | 0.63±0.005d | 12.1±0.03a | 10.2±0.06a |
| Goat | 6.0±0.009b | 0.23±0.004c | 0.05±0.01c | 0.76±0.007c | 3.8±0.01e | 4.5±0.02c |
| Sheep | 6.8±0.008a | 0.21±0.005d | 0.02±0.01c | 0.78±0.073b | 3.9±0.01d | 4.5±0.01c |
| Poultry | 4.8±0.002c | 0.95±0.004a | 0.14±0.04a | 1.02±0.008a | 3.2±0.02f | 1.5±0.01f |

Each value is the mean of three replicates with the standard deviation and values marked with the same letters in each column are not significantly different (P >0.05).

The Scanning Electron Microscopy (SEM) images for the livestock manure biochars showed significant variations in morphological structure. The biochars consisted of particles with irregular shapes, and only sheep manure biochar had some spherical shaped micro-structures. The SEM images showed that the biochars had some minor cementation of particles with some rough particles sticking on their surfaces (Figure 4.4).

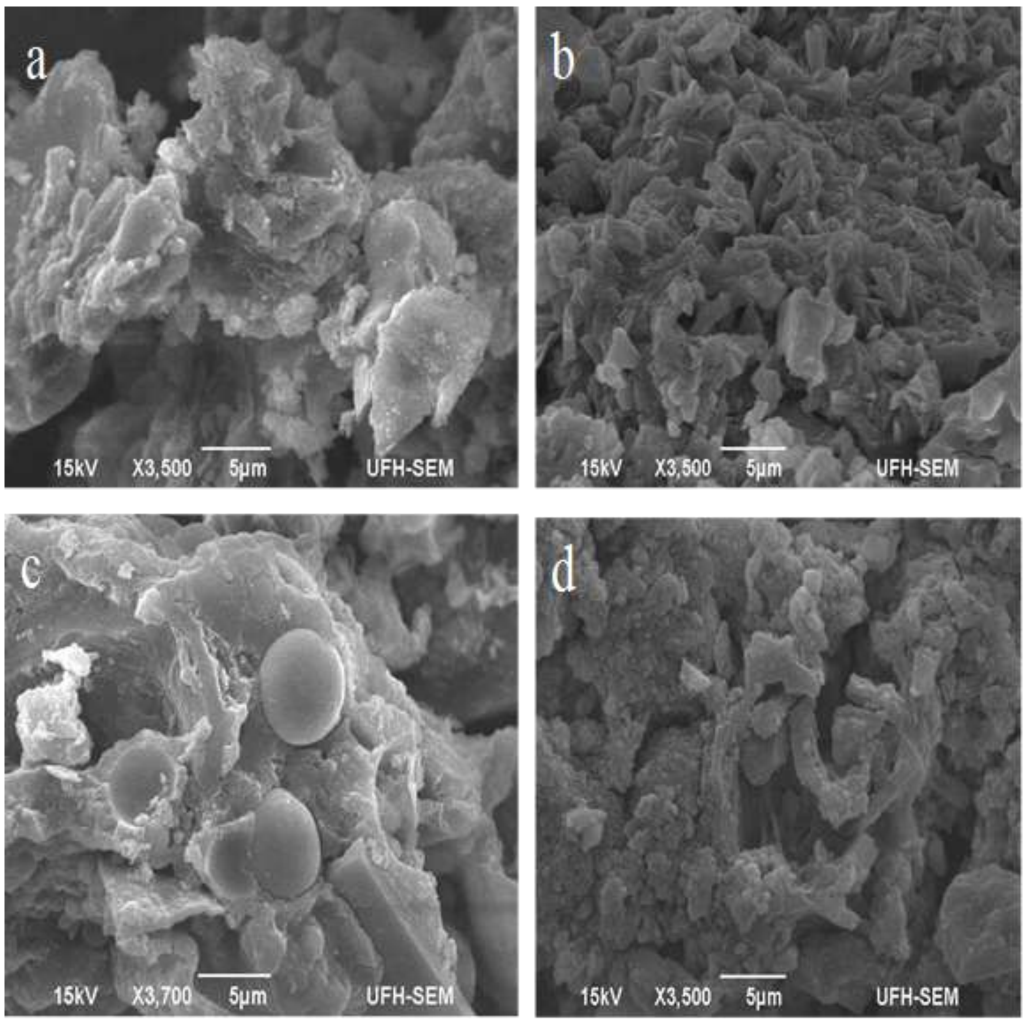


**Figure 4.4:** Scanning electron microscopy (SEM) images for the biochars produced from (a) Cattle manure, (b) Poultry manure, (c) Goat manure, and (d) Sheep manure

The SEM images were also used to calculate the microposity structures of the biochars as indicated in (Figure 4.5). Goat manure biochar showed larger surfaces with expanded pores representing a higher degree of porosity which had longitudinal microporous structures with sizes more than 4 μm in diameter. Cattle manure had an expansive network of numerous micropores ranging from 1.50 to 3 μm in diameter.

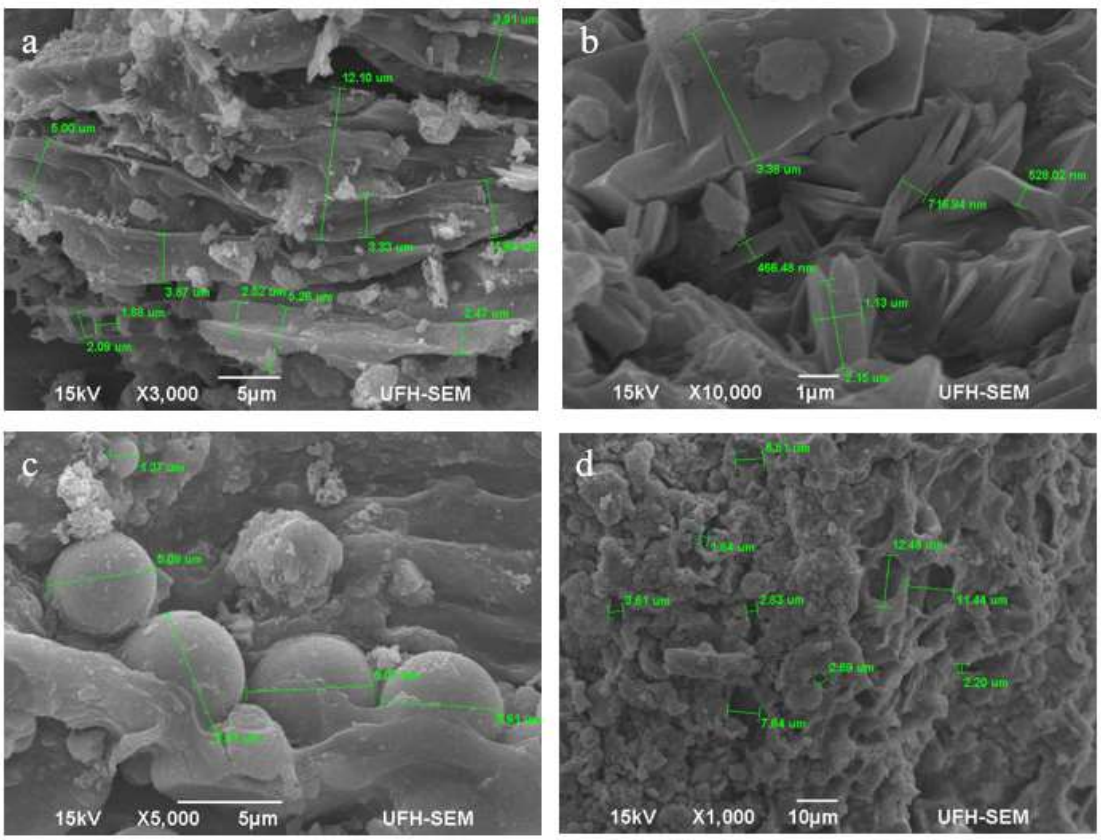


**Figure 4.5:** Scanning electron microscopy (SEM) images with diameters of micropores for the biochars produced from (a) Cattle manure, (b) Poultry manure, (c) Goat manure, and (d) Sheep manure

## 4.4. Discussions

### 4.4.1. Biochars yield and proximate analysis

Feedstock material properties including the biological, chemical and physical are known to greatly influence the yield of biochar (Stella Mary *et al*., 2016). Cantrell *et al*. (2012) observed that ash contents of the feedstock can significantly impact biochar yield, especially when such feedstock (e.g., manure) with high ash content are used. According to Vassilev *et al*. (2013) livestock manure is among the highest ash containing biomass enriched in CaO (57 %), $P_2O_5$ (15 %), and $K_2O$ (12 %) (ash analysis for chicken litter). In another study, Cely *et al*. (2014) obtained a positive correlation between char yield and ash content, and concluded that feedstock with high ash contents results in low biochar yield.

By comparing the differences in the biochar yields, we can conclude that sheep manure had high ash content, when compared with the poultry manure. This conclusion might be true since the poultry manure used for this study was broiler litter mixed with pine wood saw dust as bedding material. The proximate analysis of the livestock manure biochars were in consonance with studies conducted by Cantrell *et al*. (2012) and Cely *et al*. (2014) where feedstock from manure origin are known to result in high volatile matter and ash contents. The feedstock used in this study were manures collected from kraals except for poultry manure. Thus, the proximate results of the manures were almost similar due to similar kraal conditions and vegetation resources. The emerging results are supported by Cantrell *et al*. (2012) who reported that manure-based biochar produced at 350$^{o}$C resulted in statistically similar fixed carbon contents. This could be useful in explaining the results obtained in this study.

**4.4.2. Biochars pH and electrical conductivity**

The differences in biochars pH and electrical conductivity observed with livestock manures (cattle, goat, sheep and poultry) were sorely influenced by differences of the characteristics (origin) of the manures (Table 4.1). A study by Cantrell *et al*. (2012) evaluated the characteristics of biochars produced from a range of animal manures with two pyrolysis temperatures 350 and 700$^{o}$C and established that, pH increases were related to increases in pyrolysis temperature. Their conclusion was that the magnitude of pH increments did not only depend on increase in pyrolysis temperature, but were heavily dependent on the feedstock (manure) characteristics. This could best explain the results obtained in this study where manures were pyrolysed under a single temperature of (400$^{o}$C), in which the order of pH increases (e.g., from greatest to lowest) with pyrolysis in correspondence with the initial manure pH. Several studies such as those conducted by Hossain *et al*. (2011), Enders *et al*. (2012), and Lee *et al*. (2013) are in consonance with the current results where similar trends were observed with pyrolysis of manure feedstocks at lower temperatures (<500$^{o}$C).

The alkaline pH of the biochars obtained in this study are in consonance with studies by Gaskin *et al*. (2008), and Spokas *et al*. (2012) which indicated that these biochars could have a liming effect when applied to acidic soils. Meanwhile, electrical conductivity is an important biochar parameter for salt concentration estimation (Cely *et al*., 2014). This study showed that electrical conductivity was significantly concentrated in the respective biochars. According to Zornoza *et al*. (2016) increments in ash content are associated with high electrical conductivity, suggesting that ash is highly composed of soluble salts. The manures used in this study influenced electrical conductivity in a similar manner. Cely *et al*. (2014) further found out that the electrical conductivity of biochars from pig slurry and poultry litter mixed with sawdust decreased significantly upon pyrolysis. Dairy manure, cattle-straw manure and poultry litter electrical conductivity significantly increased with pyrolysis (Cely *et al*., 2014). The preferred soil pH for most crop growth is between 5.5 to 7.0 and the mean soil pH for soils under smallholder farming ranged between 4.8 to 5.9 (Mandiringana *et al*., 2005) and between 4.3 to 4.7 (van Averberke *et al*., 2008). Thus, biochar application can significantly ameliorate and condition soil pH when applied cautiously.

### 4.4.3. Biochars nutrient characteristics

Concentration of some elements in the biochar depends on the pyrolysis temperature and the type of feedstock (Wu *et al*., 2011). In this study, pyrolysis of livestock manures at 400$^{o}$C resulted in biochars with unique nutrient concentrations. The greater proportion of nutrient value of biochar was found in the ash content. This was consistent with Cheng and Xu (2009) who also reported that the higher the ash content of the feedstock, the higher the concentrations of Ca, Mg, Na, K, P, Cu, Zn, Al, Fe and Mn mineral elements in the produced biochars.

These results align with Touray *et al*. (2014) who produced biochar from goat manure with high Ca, Mg, P, K mineral concentration in the ash matrix of the biochars. In this study, poultry manure biochar was mostly enriched with P mineral element. Several studies have also reported P enrichment in biochar produced from poultry or chicken manures/litter (Chan *et al*., 2008; Revell *et al*., 2012; Inal *et al*., 2015). The trace of amounts of heavy metals (Zn, Cu, Al, Fe and Mn) concentrations in manure samples were reduced when compared with their biochars. Their concentrations were expected to increase as was the case, with other elements including pH and electrical conductivity. Concentrations of trace metals including Zn, Cu, and Mn were subsequently reduced with pyrolysis in all the livestock manures. This reduction in trace of heavy metals is important for agronomic application of the biochar because it reduces the impact of increasing soil heavy metal concentrations in a singular short term application (Cantrell *et al*., 2012).

#### 4.4.4. Biochars physical and structural characteristics

The physical and structural properties of biochar are important since they will interact with the physical, porosity, particle size distribution and bulk density of the soil. The bulk density (BD) of the biochars were variable. For instance, 0.75 g $cm^{-3}$ poultry manure biochar was the lowest and 0.94 g $cm^{-3}$ sheep manure biochar was the highest. The BD is an important biochar parameter whereas, the low BD biochars are excellent for use in potting soils. Based on BD, poultry manure biochar stood out to be a potential potting medium. Hydraulic properties of the biochars also varied. For example, cattle manure biochar at 141% was the lowest, whereas poultry 180% had the highest water holding capacity (WHC). These differences in BD and WHC between the biochars are much influenced by the particle size distribution, and internal and external porosity (Glaser *et al*., 2000). Biochar comprising of multiple particles and the macroporosity within each particle and the inter-particle voids affects the BD (Stella Mary *et al*., 2016). The structural properties of the biochars revealed through morphology by scanning electron microscopy showed that, goat manure had numerous pore structures which were bigger in size as compared to cattle manure. These differences in pore sizes and distribution can account for its higher porosity which is important for water holding, nutrient sorption, microbial growth and soil aeration. This is in agreement with Brewer *et al*. (2014) who mentioned that, the microscopic structures of biochar are the primary determinants in its soil amelioration properties.

### 4.5. Conclusion and recommendations

The result of this study showed that livestock manure composition were a reflection of the feeding habits and management systems and livestock manures obtained from cattle, goat and sheep kraals as well as, poultry litter manure varied significantly in their chemical properties. Thus, the chemical properties of the biochars were significantly increased relative to their feedstocks, and increases were greatest in cattle manure. However, total N as well as Zn, Cu and Mn concentrations reduced in the biochars were obtained. Biochar production with poultry manures gave higher yields as compared to goat, sheep and cattle manure. Cattle manure biochar had a high fixed carbon yield and could be best suited for carbon sequestration strategies. In addition, bulk density, structure and WHC in biochars are important in agronomy due to their influence of soil hydrological properties. Overall, the study suggests that, biochar can be an option in increasing nutrient concentration of manures, and improving their physical properties. Therefore, future research should be premised on the fact that, in order to upscale the biochar technology, the process of charring (pyrolysis equipment) and the feedstock should be appropriate for the smallholder farmers' circumstances.

# 5. CARBON AND AVAILABLE NITROGEN AND PHOSPHORUS RELEASE IN AN OAKLEAF SOIL AMENDED WITH DIFFERENT LIVESTOCK MANURE BIOCHARS

**Abstract**

Application of biochar can potentially improve soil properties but little information is available about the effects of kraal manure biochars from cattle, goat, sheep as well as, poultry litter on soil properties in the Eastern Cape (EC). A laboratory incubation experiment with four biochar treatments and a control was conducted to evaluate C, N and P dynamics in an acidic, low in organic carbon and fertility Oakleaf soil form. Application for each biochar type was calculated to raise the C level in the soil from its low level of 0.7 % C to 2 % C. This amounted to 53.2 t $ha^{-1}$ (cattle manure biochar), 48.1 t $ha^{-1}$ (goat manure biochar), 50.7 t $ha^{-1}$ (sheep manure biochar), and 40.2 t $ha^{-1}$ a (poultry manure biochar). Incubated treatments were destructively extracted at seven different sampling times to observe changes in C, N and P over incubation time. Interaction effects of biochar type × sampling time were only significant ($p \leq 0.05$) for soil pH. Ammonium-N ($NH_4^+$) concentrations were significantly ($p \leq 0.05$) increased in biochar treatments but no significant differences were obtained with sampling time. The rate of $NO_3$-N release was such that, sheep manure biochar released 2.17, cattle manure biochar 1.95, poultry manure biochar 2.18 and goat manure biochar 2.00 as compared to the control 1.61 mg $kg^{-1}$ $week^{-1}$. This was respective to 115.4%, 104.0%, 114.7%, 106.3% and 85.7% net $NO_3$-N release after 46 days of incubation. Increases were also observed on Olsen P concentrations (mg P $kg^{-1}$) which varied with biochar treatments: PMB (6.22), GMB

(6.37), SMB (6.44) and CMB (6.44) and were significantly higher than the control. The organic carbon increased with biochars in the following order: poultry manure biochar (0.84%)> cattle manure biochar (0.77%)> goat manure biochar (0.72%)> and sheep manure biochar (0.71%). Biochar types resulted in significant effects ($p \leq 0.05$) on pH, electrical conductivity, water holding capacity (WHC), organic carbon, total carbon, and $NH_4^+$-N. Sampling time resulted in significant differences ($p \leq 0.05$) for total carbon, pH, EC and WHC. The pH was also found to be increasing at all sampling times which were 16.46%, 8.51%, 15.87%, 10.93% and -1.76% net pH increase after 46 days of incubation. In conclusion, poultry and goat manure biochars were better performers on soil pH, electrical conductivty and WHC. The impact of biochar amendment on inorganic nitrogen was quite variable and nitrification was a major transformation. Soil extractable phosphorus did not result in much P release.

*Keywords*: Biochar, soil carbon, nitrogen, phosphorus

## 5.1. Introduction

Research in South Africa shows widespread deficiencies of nitrogen (N), phosphorus (P), potassium (K), as well as, secondary and micronutrients in the soil (Mandiringana *et al*., 2005; Van Averbeke *et al*., 2008). Hence, to increase crop yields and meet food supply, croplands require continuous soil fertility improvements (Lal, 2004). Livestock manure is widely applied to cropland as a soil amendment by smallholder farmers to counter nutrient limitations in soils (Mandiringana *et al*., 2005; Yoganathan *et al*., 1998; van Averbeke *et al*., 2008). It contains high levels of organic carbon (OC), N, P, K and other plant nutrients (Mkile *et al*., 2001). In Chapter 4, nutrient concentrations of the livestock manures were averaged at 2.3% N, 1% P and 3.2% K for cattle, goat, sheep and poultry manures.  However, soil benefits of livestock manure amendments are short lived and lasts for fewer seasons due to rapid soil mineralization (Yoganathan *et al*., 1998; Mnkeni and Mkile, 2006), and hence attention has been given to alternatives.

A potential approach is to transform livestock manure through pyrolysis and use the biochar produced as a soil amendment. Slow pyrolysis of livestock manure in Chapter 4 resulted in biochars with nutritional properties that were higher when compared to the feedstock manures. Research has also advocated biochar, categorised as an organic black carbon (Lehmann *et al*., 2011) to stay longer in the soil due to its nature, while providing similar benefits to fresh amendments (Calderon *et al*., 2015). Thus, the benefit of improving soil carbon and nutrient supply with biochar preparation from excess biomass and manures is suggested to not only improve soil quality and crop productivity but, to potentially decrease emissions of greenhouse gases from soil (Lehmann and Joseph, 2009; Chintala *et al*., 2014). For instance, in livestock manure, conversion to biochar has added advantages which may also slow down nutrient release and minimises leaching (Radlein *et al*., 1996), which is a global environmental threat. However, the disadvantages associated with biochar production are feedstock availability and considerable losses such as of N and P from the feedstock material (Christel *et al*., 2014; Gaskin *et al*., 2008). In Chapter 4, results for the biochars revealed considerable losses in N concentrations in the biochars when compared to their manures. This was due to volatilisation at pyrolysis temperatures which was  higher than 200$^{o}$C onwards and resulted in significant N losses (Christel *et al*., 2014).  Reported N losses with temperatures ranging from 400 to 500$^{o}$C significantly reduced N concentrations in the biochar by 69% and 76% respectively when compared to their feedstock (Gaskin *et al*., 2008). Hence, temperature is of critical value in biochar production for agronomic application, since N is a major plant element.

Biochar in the soil, like all other fresh organic amendments, undergoes mineralization through oxidation and reduction reactions (Cheng *et al*., 2006; Novak *et al*., 2015). This allows the ability to confidently predict soil response to biochar over a range of time. The impacts of redox reactions of biochar-ions on soil pH is the major determinant in nutrient dynamics. Basic cations in the biochar ash matrix such as Mg, K, and Ca can form alkaline oxides or carbonates that reacts with $H^+$ and monomeric Al hexa-aqua ion [Al $(H_2O)_6$] species common in acidic soils (Novak *et al*., 2009). Laird *et al*. (2008)

mentioned increases in soil pH due to specific absorption of organic molecules by ligand exchange with the release of $OH^-$, and the release of OH ions during reactions associated with localized microsites. The buffering of pH influences diversity and flourishment of microorganisms which influence nutrient release and transformations in the soil. Biochar, was reported to have some mineralizable fractions that can be incorporated into bacteria biomass leading to loss of carbon (Hamer *et al*., 2004). This, can have an impact in accelerating the decomposition of other forms of organic matter, such as native SOM (Wardle *et al*., 2008; Prayogo *et al*., 2014). Biochar application rate of 0.5% was found to have no effect on carbon mineralization, as compared to an application of 2% which had a significant mineralization of 20% (Prayogo *et al*., 2014). Thus, biochar soil amendment should be evaluated by following changes and transformations in soil properties that occur over a range of times (Dempster *et al*., 2012).

Application of livestock manure based biochar, especially, with high N contents has been reported to result in net N mineralization (Wang *et al*., 2012). Some biochars can also improve the retention capacity of N, $NH_4^+$-N and $NO_3^-$-N through various mechanisms including decreased $NO_3^-$-N leaching (Futija *et al*., 1991), reduced $NH_3$ volatilisation, $N_2O$ emission, and increased N immobilisation and nitrification (Clough *et al*., 2013; Bai *et al*., 2016). Biochar application was found to decrease inorganic N by decreasing the mineralization and sorption of nitrogenous compounds through its highly porous surface (Song *et al*., 2013; Knoblauch *et al*., 2011). Phosphorus in biochar releases much slowly because of the transformations that occurs during pyrolysis (Liang *et al*., 2014).

Phosphorus immobilized after pyrolysis observed for cattle manure was such that, water extractable P and Mehlich 3 extractable P decreased from approximately 50% and 65% in the raw feedstock to approximately 8% and 20% after carbonization, respectively (Dai *et al*., 2015). Understanding nutrient transformation occurring with pyrolysis is vital in increasing our understanding in general on its nutrient release dynamics, oxidation and mineralization (Cheng *et al*., 2006).

There is need to quantify the characteristics of biochar amended soil so as to understand the mechanisms of carbon and nutrient elements dynamics. The efficacy of biochar in soil is highly dependent on the nature of feedstock material from which it is produced, and its characterization might not fully provide its impact upon soil application (Jindo *et al*., 2014; Yargicoglu *et al*., 2015). Several studies (Calderon *et al*., 2015; Yuan and Xu, 2011; Darby *et al*., 2016; Zhu *et al*., 2014) have quantified the impact of biochars prepared from crop residues on mineralization, nutrient availability and acidity ameroliation. The objective of the study was to determine the nutrient release patterns of N and P from cattle manure biochar (CMB), sheep manure biochar (SMB), poultry manure biochar (PMB) and goat manure biochar (GMB] amendment in an Oakleaf soil form.

## 5.2. Materials and methods

### 5.2.1. Soil collection, analysis and biochar treatments

Soil samples were collected from an abandoned field near the Tyhume river catchment in Alice at the University of Fort Hare Research Farm (32°46' S and 26°50' E) which is at an altitude of 535 m above sea level. The soil is formed from weak physical and chemical weathering of alluvial parent material deposits. Using the South African classification system (Soil Classification Working group, 1991) the sandy loam soil was in the Oakleaf soil form (Table 5.1), Luvisol in World Reference Base (WRB) classification (IUSS Working Group WRB, 2006), and indigenously known as Santi (Manyevere, 2014). Soil samples were collected at depths of 0-20 cm using an auger. Prior to sampling the ground was cleared of all plant residues.

**Table 5.1:** Physical and chemical characteristics of the soil used in this study

| **Soil Property** | **Unit** | **Value** |
|---|---|---|
| Soil Classification | | Oakleaf |
| Textural class | | Sandy Loam |
| Sand | (%) | 62.2 |
| Silt | (%) | 22.8 |
| Clay | (%) | 15 |
| Field capacity | (%) | 22.3 |
| pH (water) | | 5.72 |
| Electrical conductivity | (mS $cm^{-1}$) | 0.18 |
| Organic carbon | (%) | 0.45 |
| Total carbon | (%) | 0.70 |
| Total nitrogen | (%) | 0.08 |
| $NH_4^+$ | (mg $kg^{-1}$) | 1.91 |
| $NO_3^-$ | (mg $kg^{-1}$) | 12.37 |
| Olsen P | (mg $kg^{-1}$) | 5.5 |

The soil was air dried, crushed and sieved (<2mm) and stored in a dry place before physical and chemical characterization. The biochar treatments were produced by slow pyrolysis at a temperature of 400$^{o}$C, as characterized in Chapter 4. Soil application of the biochars was calculated based on the difference between the targeted soil carbon content and the actual soil carbon content. Using the biochars organic carbon content, the difference required to raise the soil's carbon from 0.7% to 2% was supplemented with cattle manure biochar at 53.2 t $ha^{-1}$, goat manure biochar at 48.1 t/ $ha^{-1}$, sheep manure biochar at 50.7 t $ha^{-1}$ and poultry manure biochar at 40.2 t $ha^{-1}$.

### 5.2.2. Incubation experiment and sample analysis

A laboratory experimental study was conducted at the University of Fort Hare Soil Science Department, in Alice between end of April 2016 and early June 2016 for 46 days. The experiment was a single factor design arranged in a randomized complete block design (RCBD). Samples of cattle, goat, sheep, and poultry manure biochars were weighed and mixed with 100g of air-dried and sieved soil in 200ml plastic containers. The biochar amended soil treatments were replicated three times. Soil without biochar was used as a control. The samples were incubated in the dark at 25$^{o}$C for 46 days (Darby *et al*., 2016). Occasionally the containers were opened and closed to allow aeration. Moisture content was also adjusted gravimetrically by weighing the containers to supplement water loss to field capacity (22.4%, w/w) by adding distilled water. The samples were collected at 1, 6, 11, 18, 25, 34, and 46 days following the incubation and

3 randomly selected containers of each treatment were collected for analysis at each sampling point. A total of 105 experimental units (5 treatments × 7 sampling time points × 3 replications) were sampled. The soil samples at each sampling time were processed within 1 week after collection and kept at 4°C before processing. Furthermore, in all seven sampling points, subsamples from each container were taken for subsequent soil analysis. Following Calderon *et al*. (2015) subsamples of each soil container (three replications per treatment) were ground to fine powder and used to measure total C (TC) and total N (TN) using LEC analyzer by combustion (LECO Corporation, 2012).

The soil pH was determined using a pH meter (Crison Instruments, Spain) in a 1:2.5 (v/v) soil: water suspension without temperature adjustments as outlined by AgriLASA (2004). The study followed the soil electrical Conductivity readings which were also taken using a conductivity meter (Crison Instruments, Spain) on the same suspension used for pH reading after a 1 hour settling period (Okalebo *et al*., 2002). Furthermore, soil WHC was determined following a method outlined by Yargicoglu *et al*. (2014). The total soil carbon (C) and total N were measured by dry combustion method using a LECO TruSpec C/N auto analyser (LECO Corporation, 2003) using air-dried, ground soil. Soil organic carbon (SOC) was determined following the modified Walkley Black method (AgriLASA, 2004). Bicarbonate-extractable P (Olsen-P) was determined following procedure outlined by AgriLASA (2004), using 0.5 M Sodium bicarbonate ($NaHCO_3$) which had been adjusted to pH of 8.5. This was achieved by using 1 M Sodium hydroxide (NaOH). Mineral N ($NO_3^-$-N and $NH_4^+$-N) were extracted using 0.5 M $K_2SO_4$ followed by colorimetric determination as outlined in Okalebo *et al*. (2002). The Rate of $NO_3$-N, release, predicted and net release after 46 days of incubation were calculated following methods by Mupambwa *et al*. (2016).

### 5.2.3. Statistical analysis

Data were statistically analyzed by the fit model as a 2-way randomized block design using JMP package version 13.1 (SAS Institute Inc., 2017). This was done to investigate the significances of sampling time, biochar treatments and their interactions. The ANOVA were separately performed for each measured soil parameter and where significant differences were detected. Tukey's HSD test was used to determine which groups in the sample were significantly different at 5% level of probability. Pearson correlation coefficients and regression analysis was used to evaluate relationships between duration of incubation period and soil properties.

## 5.3. Results

### 5.3.1. Dynamic changes of soil carbon (C) from livestock manure biochars amended soil under incubation

During incubation, there were no significant differences ($p \geq 0.05$) between the biochar types, and incubation time. The results showed insignificant interactions for organic carbon and total carbon in Table 5.2. Soil organic carbon mineralization is a biochemical process dominated by the microorganisms. Soil organic carbon in all biochar treatments during the incubation was significantly ($p \leq 0.05$) higher than the control, although fluctuation was observed (Fig 5.1). Treatments which had the highest soil organic carbon were poultry manure biochar which was at 0.96% at day 6, and the lowest was 0.6% in goat manure biochar at day 18 and $46^{th}$ day of incubation (Figure 5.1). The fluctuations in soil organic carbon observed in the biochar amended treatments were significant ($p<0.05$) with the sampling times (Table 5.2).

The results showed that, biochar use as an amendment resulted in higher total carbon (TC) concentrations as compared to soil alone. The biochar treatments were consistent with application which sought to bring the level of C to 2% (Figure 5.1). All the treatments receiving livestock biochars remained significantly ($p \leq 0.001$) higher in TC throughout the incubation time though the TC mineralization rates were different with different biochar treatments at all sampling times of incubation.

**Table 5.2:** Summary analysis of variance (ANOVA) results for livestock manure biochar effects, sampling time, and interaction for dynamics in selected physical and chemical soil properties analyzed following destructive sampling over 42 days of incubation

| **SV** | | pH | EC | WHC | OC | TC | TN | $NH_4^+$-N | $NO_3^-$-N | Olsen P |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Water | mScm$^{-1}$ | -----------------%------------------- | | | | --------------mg kg$^{-1}$------------ | | |
| Biochar (B) | $F_{(4,35)}$ | 419.4 | 269.7 | 26.06 | 16.58 | 474.2 | 243.3 | 720.5 | 272.7 | 440.2 |
| | *P* | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Sampling (T) | $F_{(6, 35)}$ | 1298.5 | 223.2 | 346.7 | 0.81 | 5.94 | 45.7 | 17710.1 | 862.2 | 1415.1 |
| | *P* | <0.0001 | <0.0001 | <0.0001 | ns | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| B × T | $F_{(24, 35)}$ | 254.9 | 9.03 | 422.1 | 0.42 | 1.29 | 11.5 | 961.1 | 599.4 | 17.5 |
| | *P* | <0.0001 | <0.0001 | <0.0001 | ns | ns | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| CV (%) | | 2.60 | 4.23 | 8.75 | 6.06 | 6.71 | 3.05 | 7.63 | 6.58 | 9.43 |

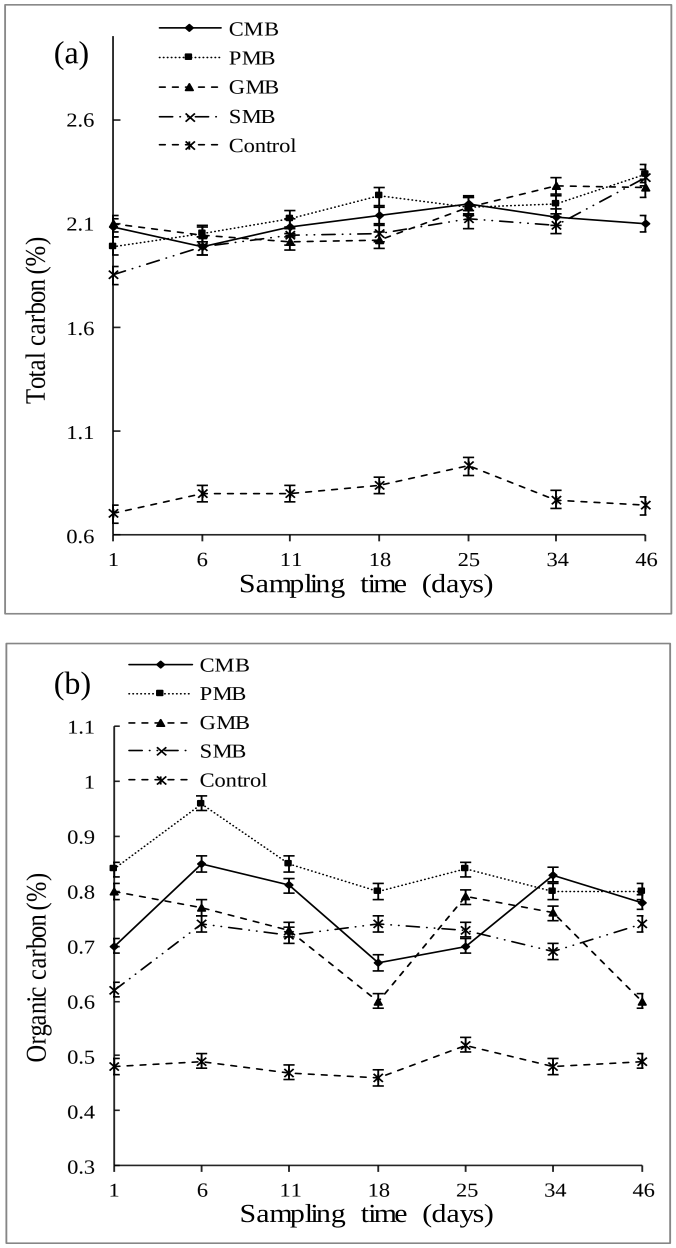


**Figure 5.1:** Changes in (a) TC (%) and (b) SOC (%) during 6 weeks of soil incubation treated at 2% C equivalent to 53.2, 48.4, 50.7, and 40.2 Mg ha$^{-1}$ for cattle, goat, sheep and poultry manure biochar, respectively.

(**CMB**)= Cattle manure biochar, (**PMB**)= Poultry manure biochar, (**GMB**)= Goat manure biochar, (**SMB**)= Sheep manure biochar, (**Control**)= No amendment

## 5.3.2. Changes in pH and electrical conductivity from livestock manure biochars amended soil under incubation

The effect of amending manure biochars from sheep, goat, cattle and poultry to an Oakleaf soil during the incubation time was variable as indicated by the highly ($p \leq 0.0001$) significant interaction (biochar type × sampling time) in pH and electrical conductivity. Generally, pH in all the four biochar treatments increased from 5.67 (control) to 5.72 during the incubation time (Fig 5.2). Treatments amended with poultry manure biochar had a value of 6.79, goat manure biochar had 6.90, sheep manure biochar 6.72, and cattle manure biochar had 6.76 (Fig 5.2). Soil electrical conductivity values were increased with the application of all four biochar types within the first 6 days of incubation time and continued to increase gradually until remaining near constant at 18$^{th}$ to 25$^{th}$ sampling times (Fig 5.2). The rate of pH increase was such that, sheep, cattle, poultry, goat manure biochars increased by 0.14, 0.08, 0.14, 0.10, and -0.02 for the control pH/week. The pH was also found to be increasing at all sampling times respective to 16.46%, 8.51%, 15.87%, 10.93% and -1.76% net pH increase after 46 days of incubation.

Electrical conductivity also increased with biochar treatments and incubation time. Electrical conductivity value for control treatments of 0.39 $mScm^{-1}$ was not significantly different from the value obtained for poultry manure biochar of 0.43 $mScm^{-1}$. however, observations were made that the electrical conductivity was significantly different from goat manure biochar, cattle manure biochar and sheep manure biochar treatments.

Electrical conductivity was also increased in the order 0.042>0.048>0.038> and 0.038 mS/cm/day for GMB, CMB, SMB and PMB, respectively. This was respective to 80%, 100%, 80.6%, and 69.4% net electrical conductivity increase after 46 days of incubation.

### 5.3.3. Inorganic nitrogen ($NH_4^+$-N, and $NO_3^-$-N) and total nitrogen (TN) release from livestock manure biochars amended in an Oakleaf soil under incubation

During incubation, there were highly significant differences ($p \leq 0.001$) between the biochar types, and incubation time as indicated by significant interactions on $NH_4^+$-N, $NO_3^-$-N and TN in Table 5.2. However, results show that biochar amendments as a soil fertility option resulted in the release of less ammonium ($NH_4^+$-N) as compared to the release of nitrate ($NO_3^-$-N) (Fig 5.3). Application of biochars resulted in increased ammonium and nitrate concentration in the first 6 days of incubation. However, ammonium began to decrease gradually from day 11 up to the end of incubation experiment, and changes were <1 mg $kg^{-1}$ (Fig 5.3). The application of four biochar treatments resulted in a sudden increase and a continuous decrease in the $NH_4^+$-N concentration of the sandy loam soil significantly ($p \leq 0.001$) during the incubation. On the whole, there were significant differences among the $NH_4^+$-N concentrations of the four biochar treatments. Poultry and sheep manure biochars had higher $NH_4^+$-N concentration of 3.59 mg $kg^{-1}$, while, the cattle manure biochar had the lowest 2.12 mg $kg^{-1}$.

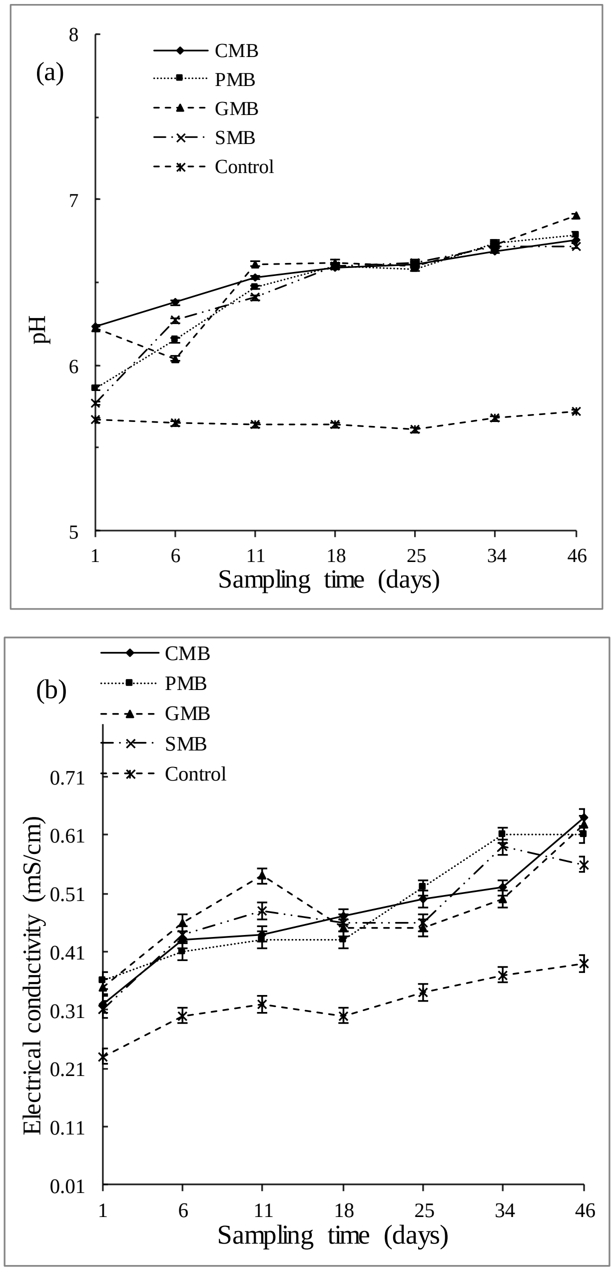


**Figure 5.2:** Changes in (a) pH and (b) electrical conductivity during 6 weeks of soil incubation treated at 2% C equivalent to 53.2, 48.4, 50.7, and 40.2 Mg $ha^{-1}$ for cattle, goat, sheep and poultry manure biochar, respectively.

(**CMB**)= Cattle manure biochar, (**PMB**)= Poultry manure biochar, (**GMB**)= Goat manure biochar, (**SMB**)= Sheep manure biochar, (**Control**)= No amendment

However, nitrate ($NO_3^-$-N) kept a slow increase trend after 6 days, and $NO_3^-$-N concentration reached 23 mg kg$^{-1}$ (control), cattle manure biochar 25.3 mg kg$^{-1}$, poultry manure biochar 26.9 mg kg$^{-1}$, goat manure biochar 25.7 mg kg$^{-1}$, and sheep manure biochar 26.7 mg kg$^{-1}$ at 46 days of incubation (Fig 5.3). During the whole incubation time, $NO_3^-$-N concentration accounted for more than 90% of soil inorganic N for all biochar treatments while, $NH_4^+$-N proportion was lower than 10%. On average, nitrification rates of the five treatments were 1.95 in cattle manure biochar, 2.18 in poultry manure biochar, 2.00 in goat manure biochar, 2.17 in sheep manure biochar, and 1.61 (control) mg kg$^{-1}$ day$^{-1}$ (Table 5.3). The four biochar treatments significantly increased soil $NO_3^-$-N content for whole incubation stage. This resulted in increases of 115.4%, 114.7%, 106.3%, 104.04%, and 85.70% for sheep manure biochar > poultry manure biochar > goat manure biochar > cattle manure biochar, and > control (Table 5.3).

### 5.3.4. Bicarbonate-extractable phosphorus (Olsen-P) release dynamics from livestock manure biochars amended soil under incubation

During incubation, there were highly significant differences ($p \leq 0.001$) between the biochar types and incubation time as indicated by significant interactions in Table 5.2. Results from the incubation study showed that Olsen-P concentration in all biochar treatments resulted in the release of P that was higher as compared to the control on the first day and showed gradual increases at all treatments up to day 11 where the Olsen-P concentrations rapidly increased and continued to increase gradually from to 18$^{th}$ to the 46$^{th}$ day (Figure 5.4).

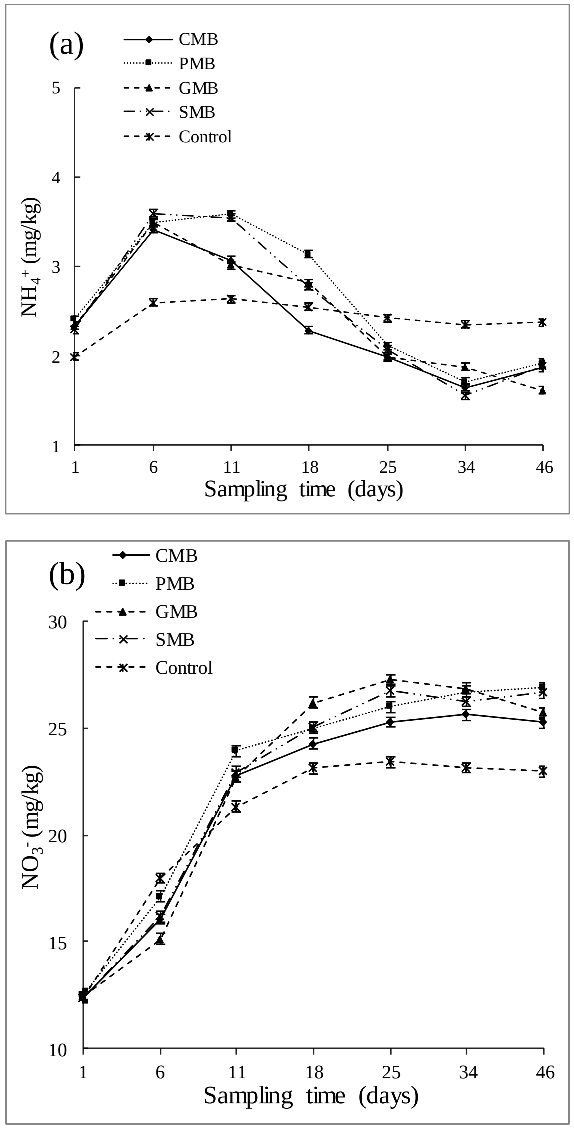


**Figure 5.3:** Changes in (a) NH4+-N (mg/kg), and (b) $NO_3$--N (mg $kg^{-1}$) during 6 weeks of soil incubation treated at 2% C equivalent to 53.2, 48.4, 50.7, and 40.2 Mg $ha^{-1}$ for cattle, goat, sheep and poultry manure biochar, respectively.

(**CMB**)= Cattle manure biochar, (**PMB**)= Poultry manure biochar, (**GMB**)= Goat manure biochar, (**SMB**)= Sheep manure biochar, (**Control**)= No amendment

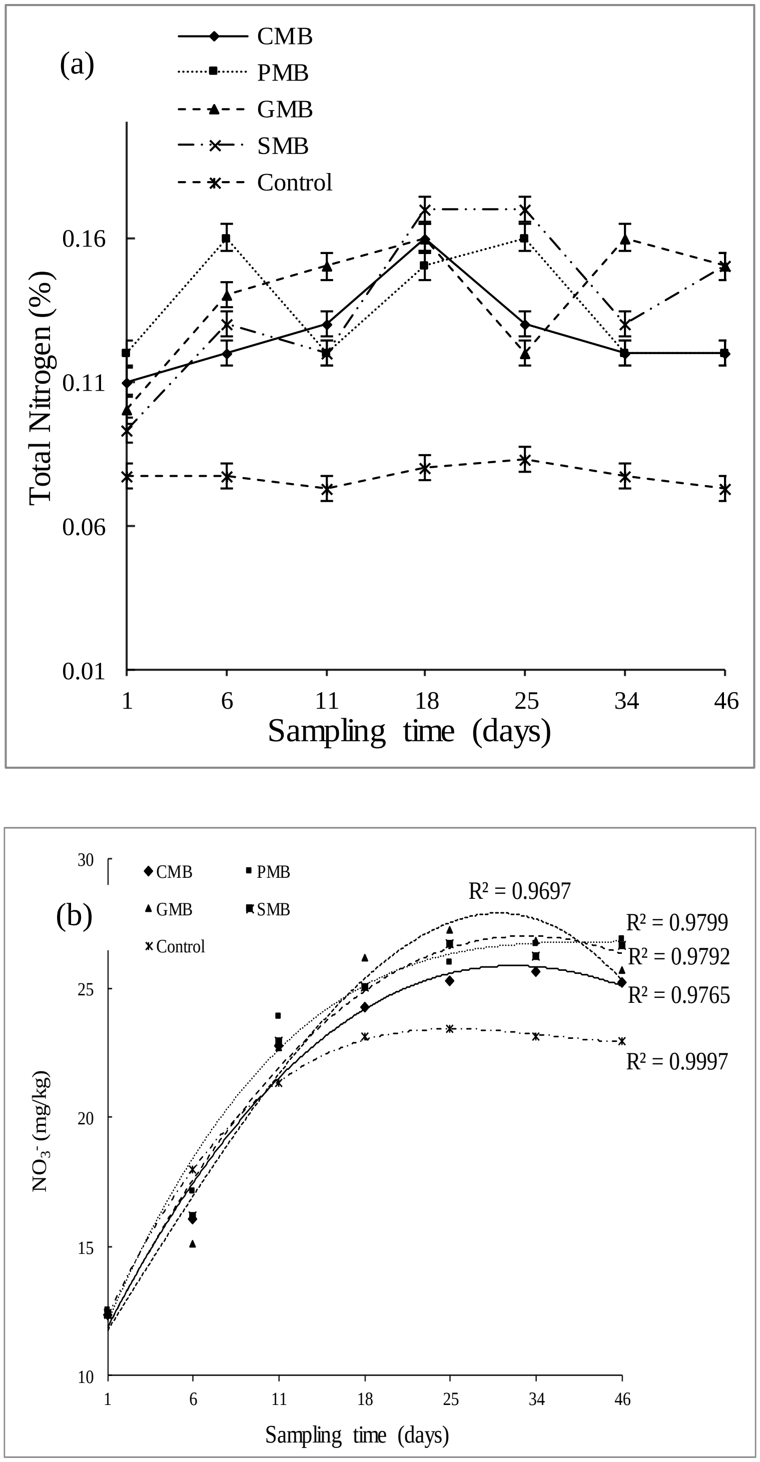


**Figure 5.4:** Effects of biochars on (a) total nitrogen (%), (b) $NO_3$--N (mg $kg^{-1}$) during 6 weeks of soil incubation treated at 2% C equivalent to 53.2, 48.4, 50.7, and 40.2 Mg $ha^{-1}$ for cattle, goat, sheep and poultry manure biochar, respectively.

**Table 5.3:** Effects of biochar soil amendments on changes in soil NO3-N during incubation of cattle, goat, sheep, and poultry livestock manure biochars

| Biochars | Regression equations | $R^2$ | Rate of $NO_3$-N release [a] | Predicted $NO_3$-N at 46 days [b] | Observed $NO_3$-N at 46 days [c] | Net $NO_3$-N increase after 46 days[d] |
|---|---|---|---|---|---|---|
| Control | $y = -0.0211x^3 – 0.1194x^2 + 4.4746x + 7.9771$ | 0.996 | 1.61 | 26.24 | 22.97 | 85.70 |
| Cattle | $y = 0.0217x^3 - 0.8921x^2 + 8.0998x + 5.6857$ | 0.977 | 1.95 | 26.52 | 25.26 | 104.04 |
| Poultry | $y = 0.0456x^3 – 1.5333x^2 + 10.41x + 3.1729$ | 0.980 | 2.18 | 26.82 | 26.92 | 114.67 |
| Goat | $y = -0.085x^3 + 0.2596x^2 + 5.0211x + 6.5843$ | 0.970 | 2.00 | 26.59 | 25.73 | 106.34 |
| Sheep | $y = 0.0928x^3 – 1.7099x^2 + 10.156x + 7.3057$ | 0.979 | 2.17 | 26.53 | 26.69 | 115.42 |

[a] Calculated as [$NO_3$-N at 46 days – $NO_3$-N at day 1]/46 days.
[b] Calculated based in regression equation.
[c] Determined as the actual $NO_3$-N after 46 days of incubation.
[d] Calculated as [$NO_3$-N at 46 days –$NO_3$-N at day1]/$NO_3$-N at day 1 × 100

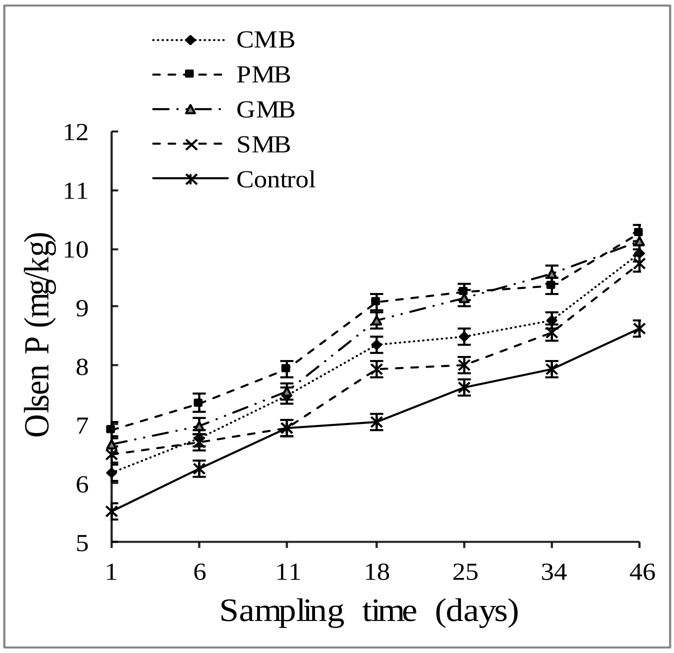


**Figure 5.5:** Changes in Olsen P (mg kg$^{-1}$) during 6 weeks of soil incubation treated at 2% C equivalent to 53.2, 48.4, 50.7, and 40.2 Mg ha$^{-1}$ for cattle, goat, sheep and poultry manure biochar, respectively.

(**CMB**)= Cattle manure biochar, (**PMB**)= Poultry manure biochar, (**GMB**)= Goat manure biochar, (**SMB**)= Sheep manure biochar, (**Control**)= No amendment

Olsen P changes did not exceed <0.5 mg kg$^{-1}$ for each sampling point during incubation (Fig 5.4). Amendments of biochar however, resulted in sudden increases significantly ($p \leq 0.05$) during the incubation. On the whole, there were significant differences among the P concentrations of the four biochar treatments. For nstance, cattle and poultry manure biochars had higher P concentrations of 6.85 mg kg$^{-1}$, while, sheep manure biochar had the lowest 6.12 mg kg$^{-1}$.

### 5.3.5. Soil water holding capacity dynamics associated with livestock manure biochars amendments to an Oakleaf soil under incubation

Livestock manure biochars from cattle, sheep, goat and poultry amendment to an Oakleaf soil during incubation time showed highly significant differences (P≤0.001) for the interaction of variables (biochar type × incubation time) on WHC.

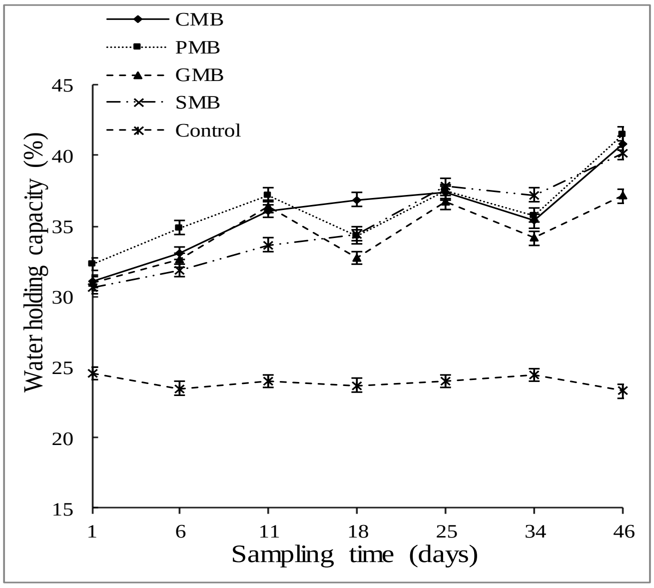


**Figure 5.6:** Changes in WHC (%) during 6 weeks of soil incubation treated at 2% C equivalent to 53.2, 48.4, 50.7, and 40.2 Mg ha$^{-1}$ for cattle, goat, sheep and poultry manure biochar, respectively.

(**CMB**)= Cattle manure biochar, (**PMB**)= Poultry manure biochar, (**GMB**)= Goat manure biochar, (**SMB**)= Sheep manure biochar, (**Control**)= No amendment

Biochar type main effects increased WHC significantly (P≤0.001) which was observed soon after the addition of biochars consistent with their high water holding capacities (Chapter 4). There was a general increase in WHC following addition of cattle manure biochar to 31.07 %, poultry manure biochar 33.31%, goat manure biochar 35.92 % and sheep manure biochar at 30.61% compared to the control (Fig 5.5) in the first day of incubation. Fluctuations which were above the controls WHC were observed and did not change significantly ($P \geq 0.05$) with incubation time. It was also noteworthy that, amendments of biochar to a soil with poor WHC can result in total improvement of the soils WHC. The greatest improvements in WHC during incubation period were obtained in soil amended with poultry manure biochar where 40.88% and these were measured on day 6 and 41.52 % on the $46^{th}$ day (Fig 5.5).

## 5.4. Discussion

### 5.4.1. Biochar effects on soil pH and electrical conductivity dynamics

The pH and electrical conductivity of the soil may influence soil functioning including nutrient availability and dynamics, redox reactions, microbial community composition, and their mass. Therefore, it is important to follow-up on these parameters in any soil fertility evaluation strategy. In this study, increases in pH and electrical conductivity obtained with the amendment of biochars from cattle, sheep, goat, and poultry manures were significant as compared with control treatment. Increase in pH with the addition of the biochars could have been due to specific adsorption of organic molecules by ligand exchange with the release of $OH^-$. During reactions associated with localized microsites (Novak *et al*., 2009; Laird *et al*., 2009), biochars contain basic cations found in the ash matrix such as Mg, K, and Ca which form alkaline oxides or carbonates that reacts with $H^+$ and monomeric Al hexa-aqua ion [Al $(H_2O)_6$] species common in acidic soils (Novak *et al*., 2009). This can explain the results obtained with biochar from cattle, goat, sheep and poultry manures significant improvements on pH and electrical conductivity. The reactions of cations introduced by biochar application, with soluble monomeric Al species displace Al species on the exchange sites resulting in a decrease in exchangeable acidity and increase soil pH (Laird *et al*., 2009). Singh *et al*. (2010) and Alburquerque *et al*. (2014) have also reported that increase in pH due to biochar application was due to the buffering effect of $CaCO_3$ in the biochars.

A study done by Chintala *et al*. (2014) showed that biochar produced from maize residue resulted in pH increases comparable to that of lime in the first 15 days of incubation. Results of the present study are in accordance with Zheng *et al*. (2013) and Yuan and Xu (2011), who obtained significant pH increases in an amended acidic soil with biochars obtained from giant reed (*Arundo donax* L.) and nine agricultural wastes namely: wheat straw, rice hull, canola straw, rice straw, corn straw, mung bean straw, peanut straw, faba bean straw, soyabean straw, respectively. In another study by (Jien and Wang, 2013) treatments amended with biochar were significantly higher in pH by at least 0.5 units than the control treatments. However, the effects of biochar on soil pH depends on the type of biochar applied, application rate and soil type. A study by Liu and Zhang (2012) where alkaline biochar of five types was amended to alkaline soils showed no pH increases. Instead, a decreasing pH trend was obtained. Prayogo *et al*. (2014) amended biochar applied at a low rate of 0.5% and obtained non significant effects on pH compared to when biochar was applied at a rate of 2% were it significantly increased pH.

An increase in electrical conductivity in the biochar treatments indicated the presence of salts in the biochar ash matrix as highlighted in Figure 5.2 (Alburquerque *et al*., 2014). The biochars utilized were of higher ash contents. Because of their high contents, electrical conductivity increases obtained in this study can be attributed to the ash contents (Chan *et al*., 2008). Meanwhile, observed increases of bases (Ca, Mg, K) in biochar-amended soil treatments compared to the control treatments in this study could be related to the salt concentration. The electrical conductivity values at different sampling times were within the appropriate range for plant growth > 10 mS $cm^{-1}$ and maize is within the sensitive range (FAO, 1994).

### 5.4.2. Biochar effects on carbon dynamics

Total organic carbon (TOC) in biochar amended soils fluctuated between about 1.8% and 2.2% throughout the incubation period and was consistent to total C content in amended soils which was brought up to a level of 2%. Limitation in C fluctuation throughout the incubation period confirmed the recalcitrant nature of the biochars and capability to withstand oxidation (Cheng *et al*., 2006) which is important in protecting organic C from depletion. This was in agreement with results of several studies which have reported resistance of biochar to mineralization in soil (Novak *et al*., 2010; Liang *et al*., 2006). Biochar amendment systematically increased SOC and this differed with the biochar type (Figure 5.1). Erratic trend was observed in biochar treatments on SOC which was generally much higher than the control. The subsequent decline in SOC indicated carbon mineralization. Darby *et al*. (2016) reported that biochars produced at low temperatures are easily mineralizable by microbes and can result in degradation of the organic fractions. However, in this study, the decrease in SOC content after treatment with biochar did not decrease significantly after 42 days of incubation, suggesting some recalcitrance to microbial mineralization. Therefore, it may be concluded that the emerging findings are important in promoting the utilization of biochar in soil carbon storage as its structure makes it stable and resistant against decomposition in the environment (Cheng *et al*., 2008; Lopez-Capel *et al*., 2016).

### 5.4.3. Biochar effects on nitrogen dynamics

Increase in $NH_4^+$-N concentrations with manure biochars treated soil compared to the control enhanced mineralization of SOM mediated by microbial activity (Schulze and Glaser, 2012; Nelissen *et al*., 2012). The release of $NH_4^+$-N from the biochar surfaces could have contributed to the increased $NH_4^+$-N thus, providing more N to the plants (Schulze and Glaser, 2012, Sarkhot *et al*., 2012). Enhanced nitrification effects after biochar amendment were reported by Gundale and DeLuca (2006). Thus, the increasing trend of $NO_3^-$-N could be best explained by the conversion of ammonium to nitrates under the influence of microbes. As such, the observed decline of $NH_4^+$-N with times was as a result of its nitrification to $NO_3^-$-N which steadily increased with time.

### 5.4.4. Biochar effects on bicarbonate-extractable phosphorus (Olsen-P) dynamics

The observed increase in Olsen extractable P with time was consistent with observations by DeLuca *et al*. (2009). They observed that biochar application increased P availability even without fresh P addition. They attributed this to possible direct release of soluble P from the biochar which is said to have substantial amounts of P in the ash matrix.

### 5.4.5. Biochar effects on water holding capacity dynamics

The results showed that soil amendment with biochars prepared from cattle, goat, sheep, and poultry manures resulted in a considerable increase in WHC of the sandy loam soil. Water holding capacity was measured gravimetrically to avoid the issues of blocked ceramic plates micropores associated with conventional pressure plate methods (Novak *et al*., 2012). In biochar amended treatments, WHC increased by about 10% relative to the control. The effect of the biochar to retain more water can be explained by several mechanisms. Increases may be related to the phenomena of hydrophilic compounds enhancing physical adsorption and or absorption of water molecules into or onto biochar (Liang *et al*., 2006; Cheng *et al*., 2008). Another possibility for the increases in water retention is indirectly related to the influence biochar has on ameliorating soil structure, through reducing bulk density and water permeability.

## 5.5. Conclusion and recommendations

The study has confirmed that soil amendment with biochar of different types at 2% C application results in improved soil organic carbon, available N and Olsen P of an Oakleaf soil and improvements were biochar type specific. Sheep manure biochar was better at ameliorating ammonium during incubation, while Olsen P release was seen to be similar with all biochars. The pH was increased with incubation and this helped in the release of nutrients. Therefore, more research needs to be carried out, to find out effects of biochar at different carbon supplementation rates so at to determine and optimize the nutrient release of the biochars.

# 6. COMPARATIVE EFFECT OF AMENDMENTS ON DEGRADED HUTTON SOIL OF DIFFERING CULTIVATION HISTORY WITH MANURE AND ITS BIOCHAR ON MAIZE SEEDLINGS GROWTH

## Abstract

There is an increasing trend in the abandonment of arable croplands in communal farming systems of the Eastern Cape, South Africa. Soil infertility coupled with erratic rainfall distribution makes cropping risky. Consequently, this influences communal farmers to focus more on farming enterprises which are of less risk like, livestock rearing resulting in arable fields of varying historical cultivation. In order to promote crop cultivation, this study was carried out to assess the effectiveness of cattle manure as a soil fertility amendment, as well as its converted biochar equivalent on a Hutton soil sampled from a smallholder farmers' field with different cultivation history. A 2 × 6 factorial glasshouse pot experiment was arranged in a randomized complete block design (RCBD) with three replications. The two factors were soil cultivation history and soil fertility amendment strategy. Soil cultivation history had two levels, in cultivation and abandoned for >5 years. The second factor was fertility strategy, which was at 6 levels namely: i. Control (soil only), ii. Manure amendment, iii. Biochar amendment, iv. Manure amendment + NPK fertilizer, v. Biochar amendment + NPK fertilizer, vi. NPK fertilization. Cattle manure was applied at 20 t $ha^{-1}$ as well as, its converted biochar equivalent. The results of the study showed that, application of biochar + fertilizer (B+F) and manure (M) resulted in maize growth that was comparable to the application of inorganic fertilizer only. Generally, biochar (B) and manure (M) treatments performed significantly ($p \leq 0.05$) different when compared to the control. Incorporation of manure + fertilizer (M+F) did not significantly ($p \geq 0.05$) differ from the application of fertilizer (F), but treatments of B+F resulted in significant differences with respect to B treatment. This study supported the suggestion that biochar alone is not a fertilizer, though its nutritional composition was comparable to that of manures. Abandoned soil was observed to have higher soil organic carbon than soil sampled from fields in cultivation. The differences in maize growth was mainly attributed to differences in initial soil properties and management in cropped fields. Further research may be needed to determine cultivation history and biochar rate of application to restore influence of soil degradation and soil fertility in the Raymond Mhlaba Municipality in order to assist farmers to improve soil fertility.

*Keywords*: Manure, biochar, cultivation history, maize growth, fertilizer, hutton soil

## 6.1. Introduction

Abandonment of cropping fields (Manyevere *et al*., 2014) and underutilization of organic and inorganic fertilizers (Mkhabela and Materechera, 2003) are pressing challenges facing smallholder farmers in South Africa. In drylands, crop production is constrained by the recurrence of drought and coupled with poor and declining soil fertility (Lal, 2004). Maize is the most common crop cultivated under the smallholder farming systems (Mandiringana *et al*., 2005; van Averbeke *et al*., 2008). It is a major source of food, contributing approximately to 55% of the African diet (Sileshi *et al*., 2008), and the stover residues are an excellent source of nutrients for livestock grazing (Yoganathan *et al*., 1998). However, poor maize yields as low as <1 t $ha^{-1}$ (Bembridge, 1984; Mkile, 2001) are often realized in areas of the Eastern Cape (EC). This influences smallholder management of cropping which is regarded as high risk and consequently receives less attention with more focus on livestock rearing (Personal communication, Krwakrwa Chief). Hence, many outfields in villages such as those in Raymond Mhlaba Municipality (Chapter 3) are no longer farmed and lie fallow. The effects of soil degradation are worsened by low fertilization input strategy which is adopted by communal farmers under conventional tillage (Mandiringana *et al*., 2005).

The great extent of the EC is underlain by parent materials that form soils of poor inherent fertility, swelling and shrinking, and susceptible to erosion (Diop *et al*., 2011). Parent material originating from basic igneous rock mineral including dolerite of the Karoo super group, and shales and mudstone of the Beufort group cover much of the central EC. According to Mandiringana *et al*. (2005) the soils are of poor fertility with dominance of quartz, mica, feldspars and kaolinitic minerals. These minerals are responsible for formation of swelling clay soil, which is highly erodible (Nciizah and Wakindiki, 2013). Conventional tillage on these inherently poor mineralogy and structure, and low fertile EC soils require proper management. Mandiringana *et al*. (2005) associated tillage with depreciation of soil quality, in which SOC levels of less than 1% were obtained on the top (1-20cm) layer of cultivated fields. Inadequate nutrient supplementation is a major problem in smallholder crop cultivation which leads to soil infertility (Mandiringana *et al*., 2005) and poor crop production (Fanadzo, 2010) which will result in cropping abandonment (Manyevere *et al*., 2014). Research that has focused on rehabilitating these soils has done this through encouraging the utilization of locally available resources such as livestock manures. Yoganathan *et al*. (1998), and van Averbeke *et al*. (2008) advocated for utilization of livestock manures to successfully improve soil fertility and crop productivity in the EC.

According to Mkhabela (2006), manure is an important nutrient resource that has recently become underutilized. Results in Chapter 3 showed that the potential dry matter manure from sheep, goat, cattle and poultry available to a household were estimated at 0.8 tonnes year $^{-1}$, 0.8 tonnes year $^{-1}$, 3.4 tonnes year $^{-1}$, and 0.0044 tonnes year $^{-1}$, respectively. Manure application rates ranging from 300 to 1820 kg ha$^{-1}$ (Yoganathan *et al*., 1998) and 123 to 2650 kg ha$^{-1}$ (Mkile, 2001) were reported in surveys conducted with crop-livestock farmers. In Chapter 3 of this study, manure application rates utilized by communal farmers ranged from 643.8 kg to 1200 kg in both homegardens and outfields. The recommended manure application rates in literature are much higher at 20 t ha$^{-1}$ (Yoganathan *et al*., 1998), showing there is underutilization. At these application rates, the amount of manure available is very limited and requires options that can improve the nutrient value.

Application of manures obtained from kraals of surrounding farmers was reported to improve soil nutrient N, P & K, availability and productivity of cabbages at early growth (8 weeks after transplanting) and late growth (16 weeks after transplanting) in the central EC (Yoganathan *et al*., 1998). Significant effects on height, stem girth and leaf number in amaranthus growth supplemented with sheep manure at a rate 50 t $ha^{-1}$ in a sandy loamy soil were obtained early after 30 days of transplanting and late, after 60 days of transplanting (Mhlontlo *et al*, 2007). Thus, it is quite clear that manure provides desirable results on soil nutrients and crop growth. However, maintaining application frequency due to rapid mineralization of its nature is quite a challenge with smallholder farmers (Mkile, 2001; Inal *et al*., 2015). As a result, due to rapid mineralization associated with fresh organic amendments, other options such as biochar are being advocated (Calderon *et al*., 2015).

Pyrolysis is a process of carbonization of biomass into biochar involving high temperatures and low oxygen supply (Lehmann *et al*., 2009). There are communities in the Raymond Mhlaba Municipality that are involved in the production of charcoal for non-agricultural purposes, and this can serve as an opportunity to investigate the agricultural uses of biochar. Pyrolysis of manure into biochar and subsequent application to soils could be a better strategy to improve manure use. Unlike fresh manure application that mineralizes quickly, biochar is carbon stable, with great potential as a sequester of carbon in the soil that enhances soil fertility properties including CEC, acidity and WHC (Sika and Hardie, 2014). Biochar produced from manure feedstock has been reported to have a higher content of nutrients as compared to biochars from non-manure origin (Cantrell *et al*., 2007). The nutrient lock could be of significant value for soil fertility and crop growth improvement. There is limited data on the usage of manure derived from biochar in SA, since most of the studies conducted focused on wood based biochars (Sika and Hardie, 2014). A number of positive effects have been reported from studies on manure based biochar, as reported by Chan *et al.*, (2008), however there is paucity of information on the effectiveness of biochar derived from manure in the African context.

Comparative studies investigating the effects of biochar to its raw feedstock are still limited, especially in Africa. Moreover, little research has been conducted on the effects of manure based-biochar on soil properties, plant growth and nutrient uptake on typical tropical soils as those in sub-Saharan Africa. Some communities in Raymond Mhlaba Municipality are using wood feedstock to produce charcoal for fuel. This is an indication that, they can also be motivated to use livestock manure as a feedstock to produce biochar, which they can apply in their fields to improve soil fertility and crop productivity whilst increasing food security at household level. Studies conducted in other countries utilizing livestock manures as feedstock have shown nutrient concentrations in the biochars compared to their manures (Chan *et al*., 2008; Uzoma *et al*., 2011; Revell *et al*., 2012; Touray *et al*., 2014). The study was carried out to determine maize growth response to cattle manure and its biochar equivalent amendment on soil of different cultivation history.

The specific objectives were to:

(i) Compare chemical properties of Hutton soil sampled in selected villages of Raymond Mhlaba Municipality from farmers fields with two cultivation histories (in cultivation, and abandoned) for > 5 years.

(ii) Determine the effects cultivation history on maize seedling growth in a Hutton soil sampled from farmers > 5 years in cultivation, and > 5 years abandonment fields amended with cattle manure at 20 t $ha^{-1}$ and its equivalent biochar application.

Hypotheses:

(i) Chemical properties of a Hutton soil sampled from farmers' fields > 5 years in cultivation, and > 5 years abandonment do not differ.

(ii) There is no difference on maize seedling growth grown in a Hutton soil sampled from farmers > 5 years in cultivation, and > 5 years abandonment fields amended with cattle manure at 20 t/ha and its equivalent biochar application.

## 6.2. Materials and methods

### 6.2.1. Soil sampling, and preparation

The survey conducted and reported in Chapter 3 was used to gather information on cultivation history of outfields in selected villages in Raymond Mhlaba Municipality, Eastern Cape, South Africa. Three representative villages, Gaga (32°45'26.63"S and 26°46'56.11"E), Krwakrwa (32°44'40.73"S 26°54'26.79"E), and Melani (32°43'24.17"S 26°52'24.28"E) were randomly selected for soil sample collection. Three replicates of soil samples were collected from the farmers fields in the villages that were cropping maize in cultivation and abandoned fields. All the fields contained one soil type with a sandy clay loam texture, which is classified as a Hutton soil form (Soil Classification Working group, 1991). This soil type is commonly known as being agricultural productive in the EC. Based on farmers' information on the cropping history of croplands survey in Chapter 3, researchers and farmers collected 42 soil samples from fields in cultivation with 1, 2, 3, 4,and 5 years of cropping, and another 42 soil samples from abandoned fields with similar years of abandonment. Soil samples were collected at depths of 0-20 cm using an auger. Prior to sampling the ground was cleared of all plant residues. The soils were transported to the drying area at the University of Fort Hare Research Farm where they were air dried, crushed, sieved (<2mm) and stored in a dry place before physical and chemical characterization.

### 6.2.2. Soil analysis

Soil samples were analyzed in triplicates. The soils collected from fields in cultivation and from abandoned fields were analysed in preparation for glasshouse experiments (Table 6.1). Soil pH was determined by using a pH meter (Crison Instruments, Spain) in a 1:2.5 (v/v) soil: water suspension without temperature adjustments as outlined by AgriLASA (2004).

**Table 6.1:** Selected properties of a Hutton soil sampled from > 5 years in cultivation and > 5 years abandonment farmers' fields

| Cultivation history | pH | Electrical conductivity | SOC | Olsen P |
|---|---|---|---|---|
| | | mS/cm | % | mg/kg |
| > 5 years in cultivation | 5.3±0.02 | 0.37±0.04 | 1.06±0.02 | 12.3±0.01 |
| > 5 years abandonment | 5.5±0.02 | 0.42±0.02 | 1.40±0.02 | 11.87±0.01 |

Each value is the mean of three replicates with the standard deviation

Soil electrical eonductivity readings were also taken using a conductivity meter (Crison Instruments, Spain) on the same suspension used for pH reading after a 1 hour settling period (Okalebo *et al*., 2002). Bicarbonate-extractable phosphorus (Olsen-P) was determined following procedures outlined by AgriLASA (2004), using 0.5 M Sodium bicarbonate ($NaHCO_3$) which had been adjusted to pH of 8.5 using 1 M Sodium hydroxide (NaOH). Soil organic carbon (SOC) was determined following the modified Walkley Black method (AgriLASA, 2004).

### 6.2.2. Treatments and experimental design

The cattle manure and biochar used are as characterized in Chapter 4. The experiment consisted of two factors, cultivation history and soil fertility amendment strategy. Soil cultivation history had two levels that is, in cultivation and abandoned for >5 years. The second factor was fertility strategy, which was at 6 levels namely: i. Control (soil only), ii. Manure amendment, iii. Biochar amendment, iv. Manure amendment + NPK fertilizer, v. Biochar amendment + NPK fertilizer vi. NPK fertilization. Cattle manure was applied at a rate of 20 t $ha^{-1}$ (Yoganathan et al., 1998), and its biochar was at 12.6 t $ha^{-1}$ (63% conversion efficiency, Chapter 4). Inorganic fertilizer was applied as straight fertilizers, which were ammonium nitrates (AN), single super phosphate (SSP), and muriate of potash (Potassium chloride) to supply 30 kg $ha^{-1}$ N, 50 kg $ha^{-1}$ P and 66 kg $ha^{-1}$ K (Van Averbeke and Marais, 1991). Nitrogen fertilizer was applied at 14 days after planting as a top dressing. This gave a 2 x 6 factorial treatment structure with a total of 12 treatments that were replicated three times and arranged in a RCBD. This was conducted in a glasshouse which had a semi-controlled environment.

### 6.2.3. Non-experimental variables

The trial was planted into pots placed on elevated tables in the glasshouse. Thirty-six perforated black polythene bags measuring 12 × 24 cm for each 6 kg of soil were utilised. Biochar application rates were calculated based on the conversion efficiency obtained in

Chapter 3, and cattle kraal manure application rate of 20 t ha$^{-1}$ was used and this was based on study conducted by Yoganathan *et al*. (1998). Application of amendments in each bag were calculated based on weight basis from the amount to be applied in a hectare. Maize open pollinated variety (OPV) ZM 1523 was planted at 3 seeds per pot and thinned to one seedling per pot 2 weeks after emergence. Pots were kept weed free by constant hand pulling of weeds that had sprouted. Irrigation water was applied to all the pots every day during hot days, and after two or three days on cold days during the first growing weeks. As the plant grew water demand increased, irrigation was applied two or three times a day in hot days and once a day in cold days to maintain the soil at 70% field capacity. Because the field capacity % moisture content is based on oven-dry soil, and the soil that was used in the polythlene bags was air-dried and contains more water than the oven-dry soil. Therefore, the amount of water in the air dried soils was calculated and adjusted using the following equations;

Air-dry percentage moisture in soil = $\frac{[Weight of\ air\ dry soil - Weight of\ oven dry soil]}{Weight of\ oven dry soil} x100$

Weight of oven dry soil to fill pot = $\frac{Weight of\ air\ dry soil to\ fill\ pot\ x100}{100 + air\ dry\%\ moisture}$

The weight of soil and water at field capacity = $\frac{[100 + field capacity\%\ moisture]\ x\ weight of\ oven dry soil}{100}$

Weight of water per pot = $weight\ of\ soil + water\ at\ field\ capacity - weight\ of\ oven\ dry\ soil$

Weight of water to add per pot = $weight\ of\ water + water\ at\ field\ capacity - weight\ of\ air\ dry\ soil$

The amount of water in this study was maintained at 70% field capacity, and was calculated by multiplying the amount of water in the soil at field capacity by the desired field capacity percentage

Weight of water per pot = $(x) \times \frac{70}{100}$

### 6.2.4. Data collection

Plants were monitored regularly and growth measurements were taken every week. The number of leaves was recorded by counting the true emerged leaves of the seedlings. Stem diameter was measured 1 cm from the base of the stem using a digital Vernier caliper. The stem diameter readings were converted to girth using the formula Stem girth = stem diameter × constant (π) (Ukonze *et al*., 2016). Plant height was measured from poly bag top soil surface up to the highest leaf tip by straightening all leaves by a tape measure. The leaf area per plant was calculated as the product of leaf length and widest middle portion of the leaf and then multiplied by a correction factor of 0.75 (Ukonze *et al*., 2016). Harvest was done at day 42 after planting and wet biomass was determined instantly. After the harvesting, the samples were oven dried at 65 degrees celcius for dry mass measurements for total dry matter.

### 6.2.5. Statistical analysis

Data for soil samples was statistically analysed by the two sample T-test using JMP package version 13.1 (SAS Institute Inc., 2017). Growth analysis was performed on a weekly basis from 14 days after planting (DAP) to 42 DAP. ANOVA was performed for a 2-way RCBD in the fit model of the JMP SAS Software as outlined by Gomez and Gomez (1984) for each growth analysis sampling day. Sources of variation were soil fertility strategy, tillage history, and interactions between variables were soil fertility strategy×cultivation history and error.

Mean separation was based on the tukey's honesty significant differences (HSD) at the 5% probability level of the F statistic.

## 6.3. Results

### 6.3.1. Differences in selected soil properties of soils sampled from > 5 years in cultivation and > 5 years abandonment farmers' fields

Table 6.2 shows the mean comparisons computed by *t*-test for soil properties sampled from farmers' fields. Soil organic carbon means were significantly ($p \leq 0.05$) different. The mean for soil sampled from fields in cultivation was 1.07±0.33 %. However, this was lower as compared to the mean of soils collected from abandoned fields (1.40±0.20 %) (Table 6.2). The pH, electrical conductivity, and extractable Olsen P of the soils were not significantly different ($p \geq 0.05$).

**Table 6.2:** Selected properties of a Hutton soil sampled from > 5 years in cultivation and > 5 years abandonment farmers' fields

| Soil parameter | In cultivation | Abandoned | t-test | |
|---|---|---|---|---|
| | | | $F_{(1, 16)}$ | P-value |
| pH | 5.28±0.41 | 5.57±0.65 | 1.274 | 0.276ns |
| EC (mS/cm) | 0.39±0.22 | 0.42±0.18 | 0.091 | 0.767ns |
| SOC (%) | 1.07±0.33 | 1.40±0.20 | 6.454 | 0.022* |
| Olsen P (mg/kg) | 12.52±4.42 | 11.85±1.96 | 0.171 | 0.685ns |

ns - Treatment not significant at P = 0.05 probability level; *, **, *** - Treatment significant at P = 0.05, 0.01 and 0.001 probability level respectively.

### 6.3.2. Effects of cultivation history and fertility strategy on maize seedling growth and total biomass yield at harvest

*6.3.2.1. Stem girth, height, and leaf number*

ANOVA revealed significant ($P \leq 0.05$) and non-significant ($P \geq 0.05$) main effects and interactions for maize growth parameters (Table 6.3). Fertility strategy × cultivation interaction for stem girth was not significant ($P \geq 0.05$). However, significant ($P \leq 0.05$) interactions on height at 42 DAP [$F_{(5, 35)} = 8.116$, P = 0.0002], and on leaf number at 14 DAP [$F_{(5, 35)} = 5.221$, P = 0.0026], 35 DAP [$F_{(5, 35)} = 6.82$, P = 0.0006] and 42 DAP [$F_{(5, 35)} = 3.749$, P = 0.0132] were observed.

Maize height at harvest (42 DAP) interaction showed that, the control was significantly better than biochar amendment in the abandoned soil, and was the same as biochar amendment in cultivated soil (Figure 6.1). Maize heights obtained with M+F (68.67cm) and F (76.03cm) in comparison to B+F (67.23cm) in cultivated and abandoned soil were not significantly different in the cultivated soil, but they were different in abandoned soil (Figure 6.1).

**Table 6.3:** ANOVA for maize parameters grown in > 5 years in cultivation and > 5 years abandonment Hutton soil, and the effects of six fertility amendment strategies, and interaction

| Treatment | Sampling time (Days after planting) | | | | |
|---|---|---|---|---|---|
| **Height** | 14 DAP | 21 DAP | 28 DAP | 35 DAP | 42 DAP |
| C | ns | ns | ns | ns | ns |
| F | ns | *** | *** | *** | *** |
| C × F | ns | ns | ns | ns | *** |
| CV (%) | 6.55 | 5.05 | 5.91 | 6.80 | 4.38 |
| **Stem girth** | | | | | |
| C | ns | ns | * | ns | ns |
| F | *** | *** | ns | ** | *** |
| C × F | ns | ns | ns | ns | ns |
| CV (%) | 12.87 | 16.73 | 16.88 | 7.63 | 3.69 |
| **Leaf number** | | | | | |
| C | ns | ns | ns | * | ns |
| F | * | * | *** | *** | *** |
| C × F | ** | ns | ns | *** | * |
| CV (%) | 15.40 | 10.05 | 8.35 | 6.28 | 5.70 |
| **Leaf area** | | | | | |
| C | ns | ns | ns | ns | ns |
| F | *** | ns | ns | ns | * |
| C × F | * | ns | * | ns | *** |
| CV (%) | 5.74 | 12.71 | 11.71 | 12.69 | 7.59 |
| **SPAD Chlorophyll** | | | | | |
| C | ns | ns | * | ns | ns |
| F | ns | ** | *** | *** | *** |
| F × C | * | ns | ns | ns | ns |
| CV (%) | 4.13 | 4.22 | 5.70 | 4.31 | 3.45 |

ns - Treatment not significant at P = 0.05 probability level; *, **, *** - Treatment significant at P = 0.05, 0.01 and 0.001 probability level respectively. C – cultivation history; F – Fertility amendment strategy; C x F – the interactions of cultivation history and fertility amendment strategy.

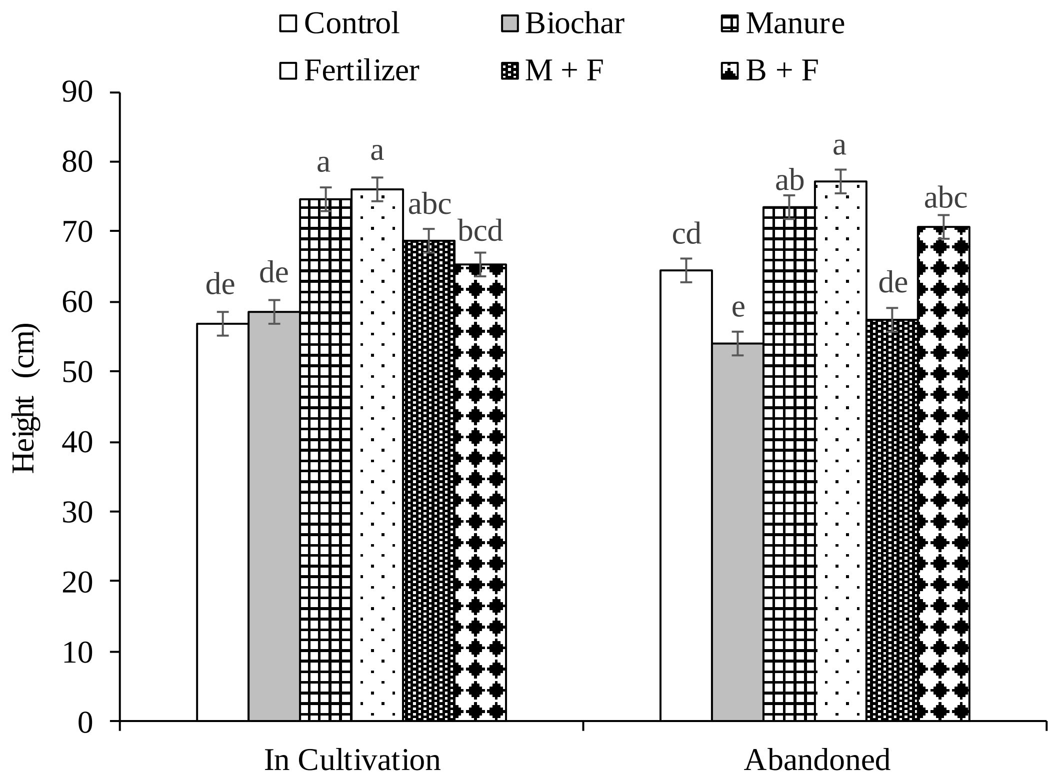


**Figure 6.1:** Interactive (C × F) effects on mean height at 42 DAP. Error bars denotes standard error of the mean, and different letters significant differences (P<0.05).

For interaction of C × F on leaf number at 14 DAP mean separation showed that, M + F treatment gave the highest mean leaf number of 3.67 in abandoned soil as compared with the soil in cultivation. On 42 DAP treatments, C (8.67), and B (9) effects on mean leaf number were significantly lower as compared to F (11) and M + F (11) treatments soil in cultivation. The control (8.67) treatment (soil in cultivation) was also significantly lower when compared with fertilizer (10.67) (Figure 6.2). However, biochar only treatment mean leaf number (10.33) in abandoned soil was significantly higher than that of soil in cultivation.

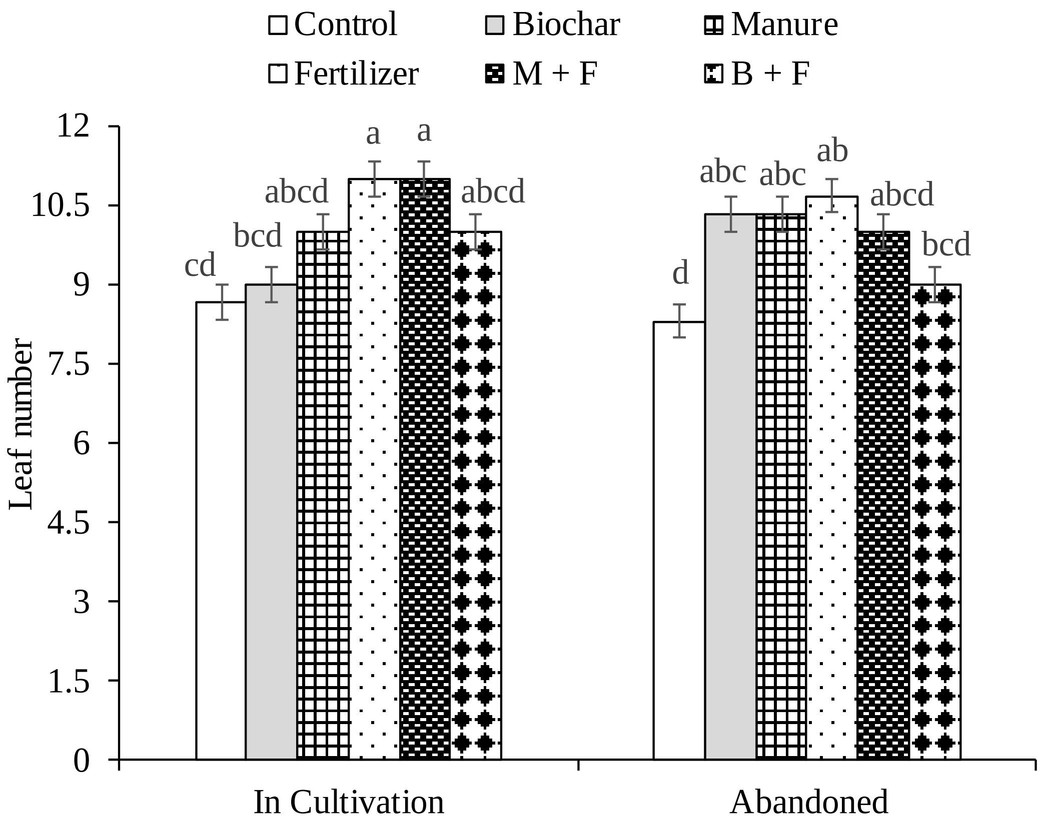


**Figure 6.2:** Interactive (C × F) effects on mean leaf number at 42 DAP. Error bars denotes standard error of the mean, and different letters significant differences (P<0.05).

*6.3.2.2. Leaf area, SPAD chlorophyll, and biomass*

Significant ($p \leq 0.05$) interactions on leaf area at 14 DAP [$F_{(5, 35)} = 3.496$, P = 0.0178], 28 DAP [$F_{(5, 35)} = 2.757$, P = 0.0443], and 42 DAP [$F_{(5, 35)} = 6.923$, P = 0.0005], and on SPAD chlorophyll at 14 DAP [$F_{(5, 35)} = 2.687$, P = 0.0484] were observed. The interactive effects at 14 DAP were such that leaf area means for fertilizer 26.9 $cm^2$ treatment in cultivated soil was significantly higher compared to B + F 21.84 $cm^2$, control 21.58 $cm^2$ (soil in cultivation), and manure 21.47 $cm^2$ (abandoned soil).

Means for leaf area at harvest, 419.99 $cm^2$ (M), 418 $cm^2$ (B + F) (soil in cultivation), and 420.1 $cm^2$ (M + F) (abandoned soil) were significantly higher than 315.21 $cm^2$ (control) (soil in cultivation), and 322.21 $cm^2$ (B + F) (abandoned soil) (Figure 6.3).

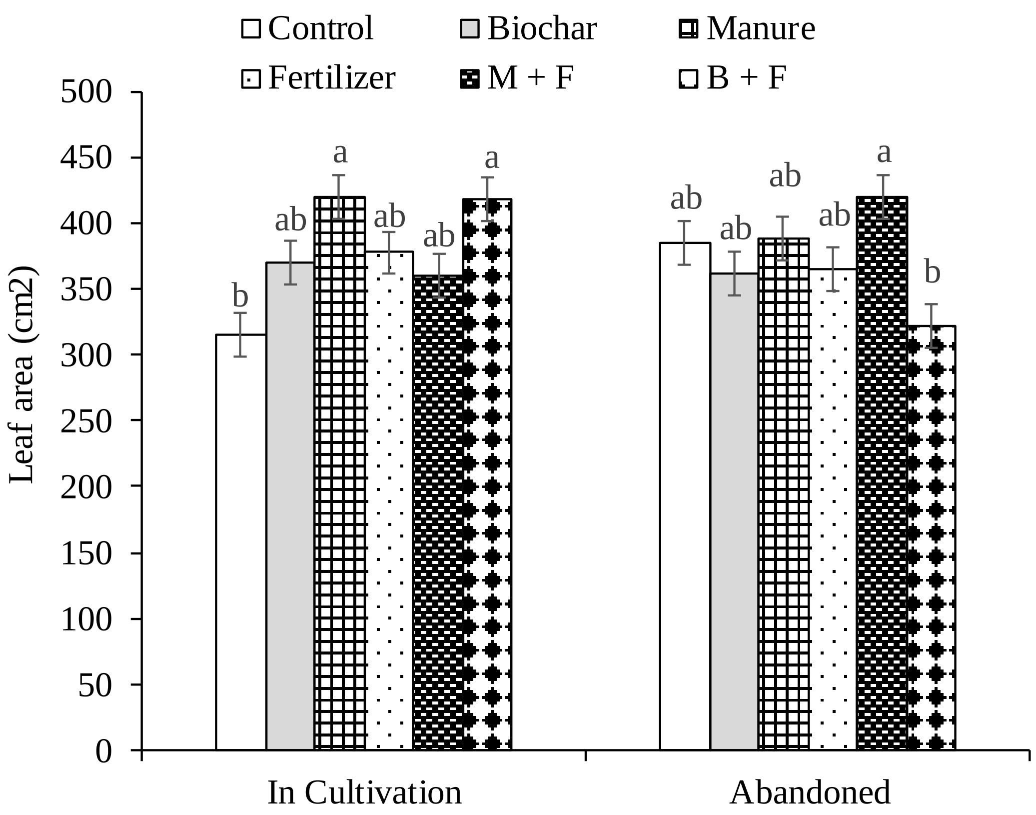


**Figure 6.3:** Interactive (C × F) effects on mean leaf area at 42 days after planting. Error bars denotes standard error of the mean, and different letters significant differences ($p<0.05$).

The interaction of C × F was not significant ($p\geq0.05$) for biomass yield. However, cultivation history and fertility strategy main effects resulted in significant ($p\leq0.05$) differences on total biomass yield. Dry biomass ranged from 10.35 to 21.5 g $pot^{-1}$ (Figure 6.4). Soil in cultivation had higher biomass yield of 15.21 g $pot^{-1}$, than abandoned soil which resulted in biomass yield of 16.37 g $pot^{-1}$. The results of the study indicated that, treatments F, M, and M + F attained the highest ($p \leq 0.05$) biomass yield, while the unamended control had the least. Biochar only and control had mean biomass yields that were not significantly different from each other and these were 11.47 g $pot^{-1}$ and 10.35 g $pot^{-1}$ respectively. But, it emerged that, yield was improved in biochar combined with fertilization treatment (Figure 6.4).

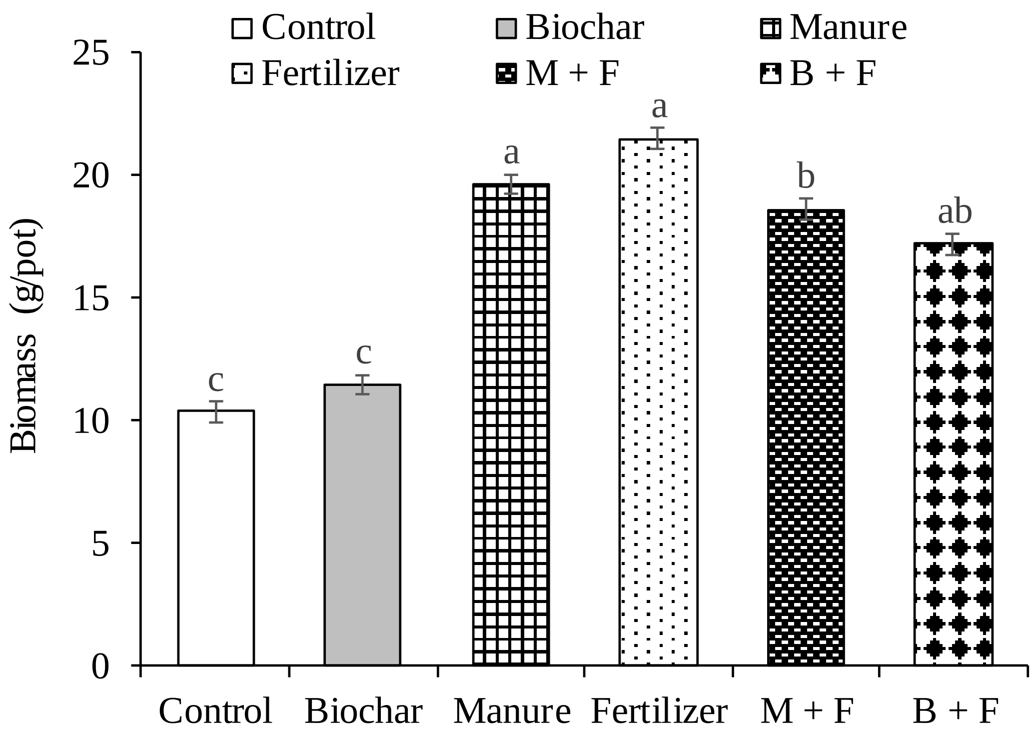


**Figure 6.4:** Mean dry biomass yields at 42 days after planting (harvest). Means with different letters are significantly different at $p<0.05$. Error bars represent standard error.

## 6.4. Discussions

### 6.4.1. Influence of cultivation history on selected soil properties

The soils used for this study had inherently low organic C contents, slightly acidic, and contained low P concentrations. Low fertilizer applications and continuous nutrient mining could have contributed to the observed low fertility (van Averbeke *et al*., 2008). Findings of this study showed that soil sampled from > 5 years in cultivation and from > 5 years of abandoned fields were significantly different in organic carbon contents. For example, abandoned fields soil samples were high in organic carbon content when compared to the soils sampled from farmers fields in cultivation. This difference may be attributed to the fact that abandoned fields somehow could have recovered in organic carbon, possibly because cultivated rainfed croplands on smallholder farms have short vegetative growth periods due to erratic rainfall resulting in low crop and root biomass. The findings of the study are in agreement with Salako *et al*. (1999) who found an increase in soil organic carbon content as the years of abandonment increased. This was associated with increasing plant biomass in the abandoned fields.

### 6.4.2. Effects of cultivation history and soil fertility management strategy on maize seedling growth

This study showed that amendment of livestock manure biochar to soils of differing cultivation histories sown to maize could increase growth and biomass yield at the early stages. Biochar combined with inorganic fertilizer (B+F) and manure alone (M) had plant growth and number of leaves similar to application of inorganic fertilizer (F). These results suggest that, these fertility strategies can effectively be used in combination with inorganic fertilizer without adverse impacts of plant growth (Schulze and Glaser, 2012). However, maize growth was improved in abandoned soil than it was in cultivated soil. This suggest that fertility recovery of soils in abandoned farmers' fields over time. Chemical characterization of sampled soils indicated insignificant differences of cultivation history, and the results of the study  may imply that farmers could have abandoned their fields for other reasons other than soil infertility.  Manyevere *et al*. (2014) supports the resuts of the study and associated an increasing rate of arable cropping land abandonment in the EC to factors such as labour shortage, high elderly population and drought reoccurrence.

Combining inorganic fertilizer with biochar (B + F), and manure (M + F) resulted in improved maize growth. This suggest that fertility amendments can be effectively used in combination with inorganic fertilizer. However, biochar cannot be used equally as with manure alone as a fertility amendment. This is supported by findings of this study where, biochar alone treatments from germination to 21 DAP showed no significant difference with the unamended control treatments in terms of height, number of leaves and stem girth at ($p \leq 0.05$). The results of the study are also commensurate with earlier studies which found that biochar application should not be substituted for a fertilizer. For instance, a study conducted by Novak *et al*. (2009) reported reduced plant growth in biochar treatments that did not receive inorganic fertilizer. Reduced growth in biochar only treatments could be due to absence of plant available forms of mineral elements, and this might have minimised maize growth measured because there are limited or  there were no nutrients to improve plant growth.

Biomass yield attained in manure alone was similar to that of fertilizer which indicates good nutrient supply potential of the manure used. The observed limit in nutrient supply of biochar was comparable to the control (no amendment) in terms of biomass yield which further confirms the notion that biochar is not a fertilizer. However, combining biochar + fertilizer attained higher biomass yield which was not significantly ($p \geq 0.05$) different to the manure alone and manure + fertilizer treatments. This observation suggests that, biochar plays a role in nutrient dynamics and has some potential in decreasing nutrient leaching. However, in this study biomass yield attained in biochar + fertilizer treatments were lower as compared to that observed for inorganic fertilizer treatments.The findings of the study are contradictory to previous studies which reported that biochar used to improve the efficiency of applied inorganic fertilizer, where treatments with biochar + fertilizer had better plant growth and biomass yield as compared to inorganic fertilizer alone (Chan *et al*., 2008; Uzoma *et al*., 2011).

On the other hand, the soil history did not appear to have a large influence on maize growth performance. However, amendment with organic amendments and fertilizer subsequently increased biomass yield. This means that B + F can be a good combination for resource poor farmers since it improved biomass productivity comparable to treatments that were receiving inorganic fertilizer. This is in agreement with Kimetu *et al*. (2008) who showed that combining biochar and inorganic fertilizer doubles soil fertility enhancement in a degraded soil when compared to the control.

## 6.5. Conclusion and recommendations

This study has demonstrated that soil sampled from the abandoned farmers fields were high in soil organic carbon, but low in pH and olsen P when compared to soil from fields in cultivation. Inorganic fertilizer application treatments perfomed better in all soil cultivation histories on maize growth, but there was no difference with manure, and manure + fertilizer treatments. Biochar alone treatments were not significantly different with control treatments. In abandoned soil, the control performed better than the biochar treatments. In general, the improvements in both soil cultivation histories was contributed to nutrients supplied in the manures and inorganic fertilizer. Combining biochar and inorganic fertilizer improved maize growth.

# 7. EFFECT OF SOIL TYPE, MANURE BIOCHAR TYPE AND APPLICATION RATE ON GROWTH OF MAIZE SEEDLINGS AND SOIL CHEMICAL PROPERTIES

**Abstract**

Agricultural application of biochar in soil provides safe, long term carbon sequestration, ameriolating soil acidity, improving nutrient availability and use by crops. Furthermore, biochar rate of application is highly depended on biochar type and soil properties. A glasshouse experiment was conducted at the University of Forthare Agronomy. The objective was to evaluate the effects of cattle, goat, poultry and sheep kraal manure biochar soil amendment at different carbon application rates on the chemical properties, and the growth of maize (*Zea Mays* L.) seedlings. The study was a 2 × 4 × 5 factorial experiment in a randomized complete block design (RCBD) with three replicates. The study found out that the amendments in soil at different rates significantly improved soil pH, electrical conductivity and Olsen P in an Oakleaf as compared to Tukulu soil. Interaction of biochar type and rate of application had no significant influences on soil properties. However, the pH of soil with biochar application at 300 and 400 kg C ha$^{-1}$ in the Oakleaf was comparable to control in the Tukulu. Soil electrical conductivity was significantly affected in the Tukulu as compared to the control biochar treated pots which had higher plant heights and number of leaves. At 400 kg ha$^{-1}$ biochar application rate growth was improved, although there was no significant difference with biochar application at 300 kg ha$^{-1}$. The total of dry maize biomass yields were significantly increased with rate of biochar application. The results of this study implied that, improvements in soil chemical properties with biochar type and rate of biochar application influenced maize growth positively, especially in an Oakleaf soil. In some instances, the control performed better than the biochar amended treatment, leading to the conclusion that much of the maize growth effect was due to inherent soil fertility and direct nutrient addition from the inorganic fertilizer.

*Keywords*: Biochar type, biochar rate, plant growth

## 7.1. Introduction

Crop outputs are often severely constrained by complex interacting factors such as rapid nutrient depletion, soil acidity, limited organic matter and limited farmers' resources (Onasanya *et al*., 2009). Pyrolysis of livestock manures has been shown to result in significant volatilization of nitrogen (Gaskin *et al*., 2008). Nitrogen (N) was reported to start volatilizing at temperatures as low as 200$^{o}$C and alterations occurring during carbonizations have long term influence on N availability. Although biochar preserves some fraction of nutrient elements in the ash matrix (Gunes *et al*., 2014), the resulting charcoal materials have high C/N ratio (Calderon *et al*., 2015). In addition, low C/N ratios in organic amendments are associated with $NH_3$ volatilization. Hence, the application of biochar to the soil can improve N use efficiency through immobilization (Prayogo *et al*., 2014) and reduce leaching (Singh *et al*., 2010). Thus, biochar application can result in improved fertilizer use efficiency through locking and releasing nutrients. This mineral lock in manure processed biochars makes them potential sources of slow-release fertilizers for crop production (Cantrell *et al*., 2012).

Biochars have been proven to enhance efficiency and reduce the need for chemical fertilizers (Schulz and Glaser, 2012). Improvement in water retention helps in soil nutrient absorption and makes plant nutrients readily available for uptake (Singh *et al*., 2010). The general positive response of crops to biochar application is principally a response to an increase in soil pH and nutrient (Ca, Mg, P and K) supply (Calderón *et al*., 2015; Alburquerque *et al*., 2014; Uzoma *et al*., 2011). On the other hand, negative plant growth responses with biochar can be linked to immobilization of soil N (Naval *et al*., 2010). Thus, changes in soil chemical properties under controlled conditions arising from the application of biochar can be quantitatively assessed using early crop growth patterns as they are sensitive to changes in soil quality.

Several studies involving the application of livestock manure-based biochars reported improvement in early crop growth relative to control (no biochar) treatments (Chan *et al*., 2008; Uzoma *et al*., 2011; Inal *et al*., 2015). Positive early maize growth (after 90 days) involving cattle manure biochar application resulted in significant height and number of leaves improvements as compared to the control (Uzoma *et al*., 2011). Poultry manure biochar application was found to increase dry matter yields of maize grown in glasshouse for 6 weeks. These improvements were positively correlated to crop yield improvements during harvesting (Inal *et al*., 2015). Studies have shown both soil chemical properties and crop growth to respond differently with amendment of varying biochars at variable application rates (Chan *et al*., 2008, Uzoma *et al*., 2011). In some instances, maize yields were reported to drop with increasing biochar application rate (Uzoma *et al*., 2011). Hence, the aim of this study was to determine the effects of cattle, goat, poultry and sheep manure biochar amendment on soil chemical properties and maize seedling growth.

The objectives of study were to:

(i) Compare the chemical properties of an Oakleaf and a Tukulu soil amended with cattle, goat, sheep and poultry manure biochar types and at 100, 200, 300, 400 kg C $ha^{-1}$ application rate at harvest of maize seedlings.

(ii) Determine the effects of an Oakleaf and a Tukulu soil type, amended with cattle, goat, sheep and poultry manure biochar type, and at 100, 200, 300, 400 kg C $ha^{-1}$ application rates on maize seedling growth

Hypotheses:

(i) Post-harvest soil chemical properties of an Oakleaf and a Tukulu soil amended with cattle, goat, sheep and poultry manure biochar types and at 100, 200, 300, 400 kg C $ha^{-1}$ application rates at harvest of maize seedlings do not differ.

(ii) There is no difference on maize seedling growth grown in an Oakleaf and a Tukulu soil type, amended with cattle, goat, sheep and poultry manure biochar type, and at 100, 200, 300, 400 kg C $ha^{-1}$ application rates

## 7.2 Materials and methods

### 7.2.1. Experimental factors, treatments and design

The experiment consisted of three factors; soil type, biochar type and biochar application rate. Two soil types, a sandy loam (Oakleaf) soil described in section 5.3.1 and a clayey loam (Tukulu) soil collected from smallholder farmer's field in Msombomvu (MSBV) village were included in the glasshouse study. The MSBV village soil was collected and prepared as outlined in section 5.3.1. Some selected characterization of the soils are presented in Table 7.1.

**Table 7.1:** Selected soil properties of soil used for the biochar amendment glasshouse study

| Soil Property | | Soil 1 | Soil 2 |
|---|---|---|---|
| | **Unit** | **Value** | **Value** |
| Soil Classification | | Oakleaf | Tukulu |
| Textural class | | Sandy Loam | Clayey Loam |
| Sand | (%) | 62.2 | 14.2 |
| Silt | (%) | 22.8 | 34.2 |
| Clay | (%) | 15 | 51.6 |
| Field capacity | (%) | 22.3 | 38.4 |
| pH (water) | | 5.72 | 8.28 |
| Electrical conductivity | (mS $cm^{-1}$) | 0.18 | 1.01 |
| Organic carbon | (%) | 0.45 | 0.91 |
| Total carbon | (%) | 0.70 | 1.1 |
| Total nitrogen | (%) | 0.08 | 0.13 |
| Olsen P | (mg $kg^{-1}$) | 5.5 | 11 |

Biochar materials used are described in Chapter 4. The second factor was the biochar type namely, cattle manure biochar (CMB), goat manure biochar (GMB), sheep manure biochar (SMB) and poultry manure biochar (PMB). These are all described in Chapter 4. The third factor was application rate of biochar which had five levels at 0, 100, 200, 300, and 400 kg C $ha^{-1}$. Biochar application rates were calculated based on the required carbon application (Table 7.2). This gave a 2 × 4 × 5 factorial treatments structure with a total of 40 treatments that were replicated three times and arranged in randomized complete block design (RCBD) in a glasshouse which has a semi-controlled environment.

**Table 7.2:** Biochar treatments and actual rates used for each carbon desired application rate based on biochar carbon contents

| Treatments (kg C $ha^{-1}$) | **100** | **200** | **300** | **400** |
|---|---|---|---|---|
| **Equivalent biochar rates (t $ha^{-1}$)** | | | | |
| Cattle manure biochar (CMB) | 0.38 | 0.76 | 1.141 | 1.521 |
| Goat manure biochar (GMB) | 0.34 | 0.69 | 1.031 | 1.375 |
| Sheep manure biochar (SMB) | 0.36 | 0.73 | 1.087 | 1.449 |
| Poultry manure biochar (PMB) | 0.29 | 0.58 | 0.86 | 1.149 |

### 7.2.2. Non experimental variables

The trial was planted into pots placed on elevated tables in the glasshouse. One hundred and twenty perforated black polythene bags measuring (12 cm in diameter × 24 cm in height) were filled with 6 kg of soil. The amount of biochar applied in each bag was calculated on weight basis from the amount of biochar that was applied in each hectare.

**Table 7.3:** Actual amount of biochar used in a bag for each carbon desired application rate

| Treatments (kg C $ha^{-1}$) | **100** | **200** | **300** | **400** |
|---|---|---|---|---|
| **Equivalent biochar rates (g $pot^{-1}$)** | | | | |
| Cattle manure biochar (CMB) | 1.14 | 2.28 | 3.42 | 4.56 |
| Goat manure biochar (GMB) | 1.02 | 2.07 | 3.09 | 4.11 |
| Sheep manure biochar (SMB) | 1.08 | 2.19 | 3.26 | 4.35 |
| Poultry manure biochar (PMB) | 0.87 | 1.74 | 2.58 | 3.45 |

Maize open pollinated variety (OPV) ZM 1523 was planted at 3 seeds per pot and thinned to one seedling per pot 2 weeks after sprouting. Inorganic fertilizer was applied on weight basis as straight fertilizers, these were ammonium nitrate (AN), single super phosphate (SSP), and muriate of potash (Potassium chloride) to supply half of 30 kg $ha^{-1}$ N, 50 kg $ha^{-1}$ P and 66 kg ha$^{-1}$ K (Van Averbeke and Marais, 1991). Nitrogen fertilizer was applied at 14 days after planting as a top dressing. The pots were kept weed free by constant hand pulling of weeds that emerged. Irrigation water was applied to all the pots every day during hot days, and after two or three days on cold days during the first growing weeks. But, as the plant grew, the water demand increased and irrigation was applied two or three times a day in hot days and once a day in cold days to maintain the soil at 70% field capacity.

### 7.2.3. Analysis of post-harvest chemical properties of soil-biochar mixtures

The initial chemical properties of the soil and biochar were determined following the procedures as outlined in Chapter 5. Post-harvest, soil samples were determined as described by Inal *et al*. (2015), the available P was determined using the Olsen P method. In addition, electrical conductivity and pH were determined potentiometrically in a 1:10 suspension of sample in distilled water as described in Chapter 5.

### 7.2.4. Plant growth data collection

Plants were monitored regularly and measurement of number of leaves and plant height was taken on a weekly basis. The leaf number was recorded by counting the true emerged leaves of the seedlings. Plant height was measured from poly bag top soil surface up to the highest leaf tip by straightening all leaves by a tape measure. Harvest was done at day 42 after planting and wet biomass was determined instantly and afterwards, the samples were oven dried at 65$^{o}$C for dry mass measurements.

### 7.2.5. Statistical analysis

Data for soil chemical analysis and plant growth including total biomass yields were subjected to factorial Analysis of Variance (ANOVA) to evaluate treatment effects. The Fit Model (FM) option in the ANOVA programme of JMP software package version 13.1 (SAS Institute Inc., 2017), as outlined by Gomez and Gomez (1984) was adopted. Mean separations were based on the Tukey's HSD test at the 5% probability level.

## 7.3. Results

### 7.3.1. Influence of biochar type, and biochar rate on post-harvest chemical properties of an Oakleaf and a Tukulu soil

Table 7.4 shows analysis of variance (ANOVA) results for soil chemical properties measured after maize harvest. The three-way interaction between biochar type × soil type × rate was not significant ($p>0.05$) and neither was the two-way interaction between biochar type × rate. Biochar type × soil type was significant only with respect to electrical conductivity ($p<0.001$).

**Table 7.4:** ANOVA for data on post-harvest soil pH, electrical conductivity, and Olsen P

| | **Post-harvest soil properties** | | |
|---|---|---|---|
| **Treatment** | pH | Electrical conductivity | Olsen P |
| Biochar type (Bt) | ns | *** | * |
| Biochar rate (Br) | *** | *** | *** |
| Soil type (St) | *** | *** | *** |
| Bt × Br | ns | ns | ns |
| Bt × St | ns | *** | ns |
| Br × St | *** | ** | ns |
| Bt × Br × St | ns | ns | ns |
| CV (%) | 6.14 | 9.45 | 9.72 |

Biochar rate × soil type was significant with respect to pH ($p<0.001$) and electrical conductivity ($p<0.01$) but, not Olsen P ($p>0.05$). Main effects of biochar type were significant with respect to electrical conductivity ($p<0.001$) and Olsen P ($p<0.01$) but, not pH ($p>0.05$). Main effects of biochar rate and soil type were significant with respect to pH, electrical conductivity and Olsen P ($P<0.001$) as indicated in (Table 7.4).

The Br × St interaction with respect to soil pH is presented in Figure 7.1 and shows that the control (no biochar) in the Tukulu soil was significantly better than biochar amendment at 100 and 200 kg C $ha^{-1}$ in the Oakleaf soil. Biochar amendment at 300 and 400 kg C $ha^{-1}$ in the Oakleaf soil was not significantly different to the control (no biochar) in the Tukulu soil. This was the same as biochar amendment at 200 kg C $ha^{-1}$ in the Tukulu soil as illustrated in (Figure 7.1).

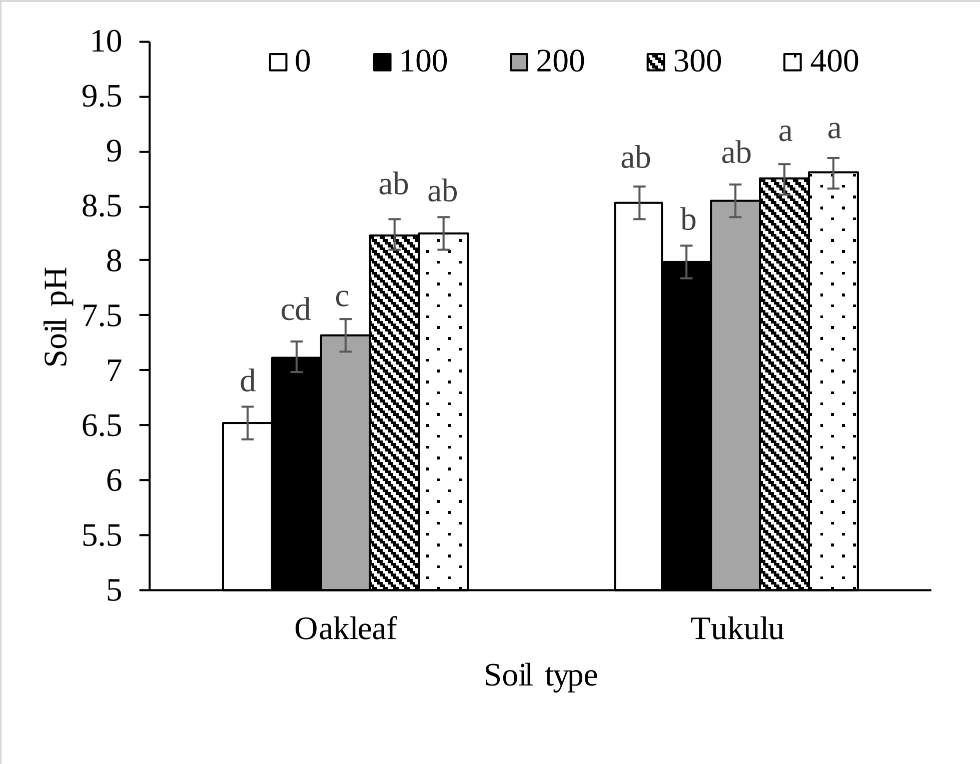


**Figure 7.1:** Interactive (Br × St) effects on post-harvest soil pH. Error bars denotes standard error of the mean, and different letters significant differences ($p<0.05$)

The Br × St interaction with respect to electrical conductivity is presented in Table 7.4 and shows that the control in the Tukulu soil had significantly higher electrical conductivity as compared to biochar amendment at 400 kg C $ha^{-1}$ in the Oakleaf soil. On the other hand, the electrical conductivity values were not significantly different to biochar application at 300 kg C $ha^{-1}$ in the Oakleaf soil. Biochar application at 200 kg C $ha^{-1}$ in the Tukulu soil resulted in higher electrical conductivity as compared to similar applications of 300 kg C $ha^{-1}$ in Oakleaf soil. The results further showed that, there were no significant differences to electrical conductivity which were observed at application rate of 100 kg C $ha^{-1}$ biochar in the Tukulu soil as compared to application of 200, 300 and 400 kg C $ha^{-1}$ (Figure 7.2).

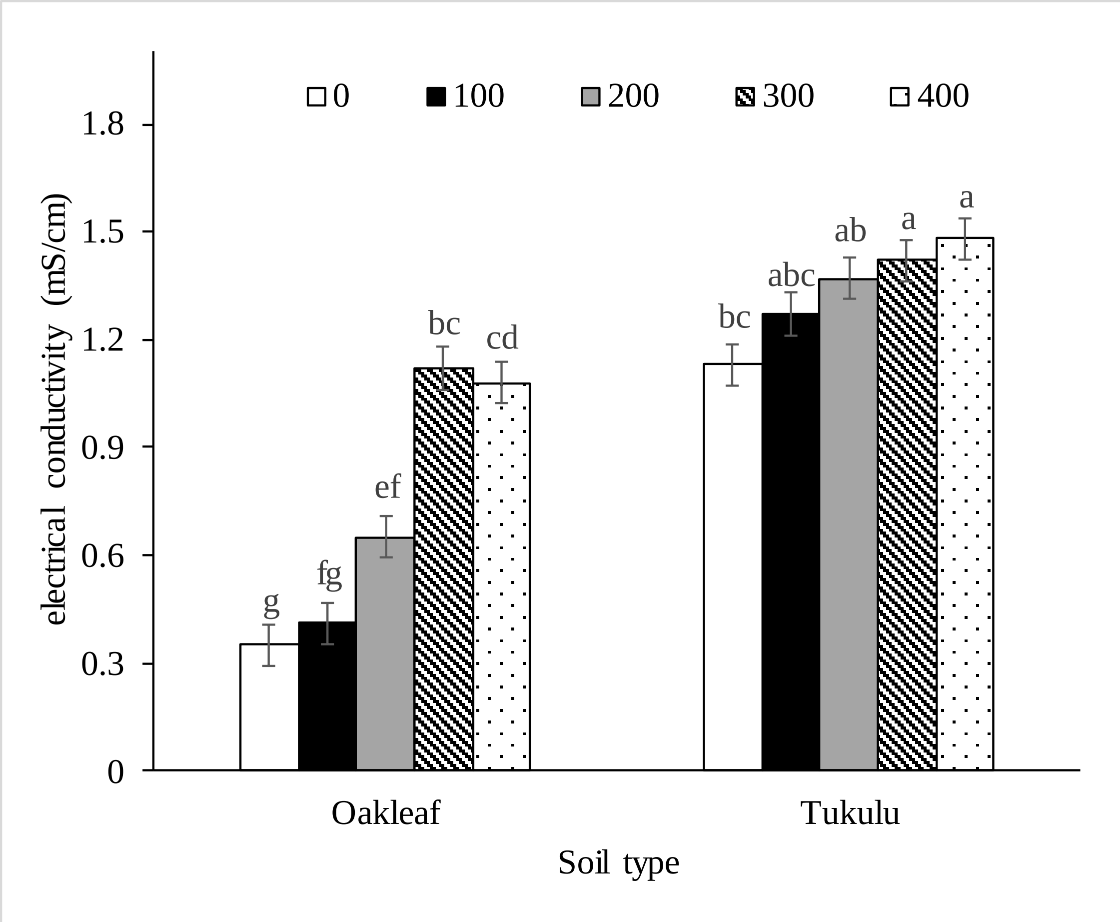


**Figure 7.2:** Interactive (Br × St) effects on post-harvest soil electrical conductivity (mS $cm^{-1}$). Error bars denotes standard error of the mean, and different letters significant differences ($p<0.05$).

The Bt × St interaction with respect to electrical conductivity is presented in Figure 7.3. On overall, the amendment of biochar resulted in non significant differences of electrical conductivity within the soil type but, significant differences were obtained across soil types. Biochar type amendment increased the soil's electrical conductivity similiary, this was also observed in the different soil types. But, significant different increases in electrical conductivity were obtained with sheep manure biochar amendments in the Oakleaf soil.

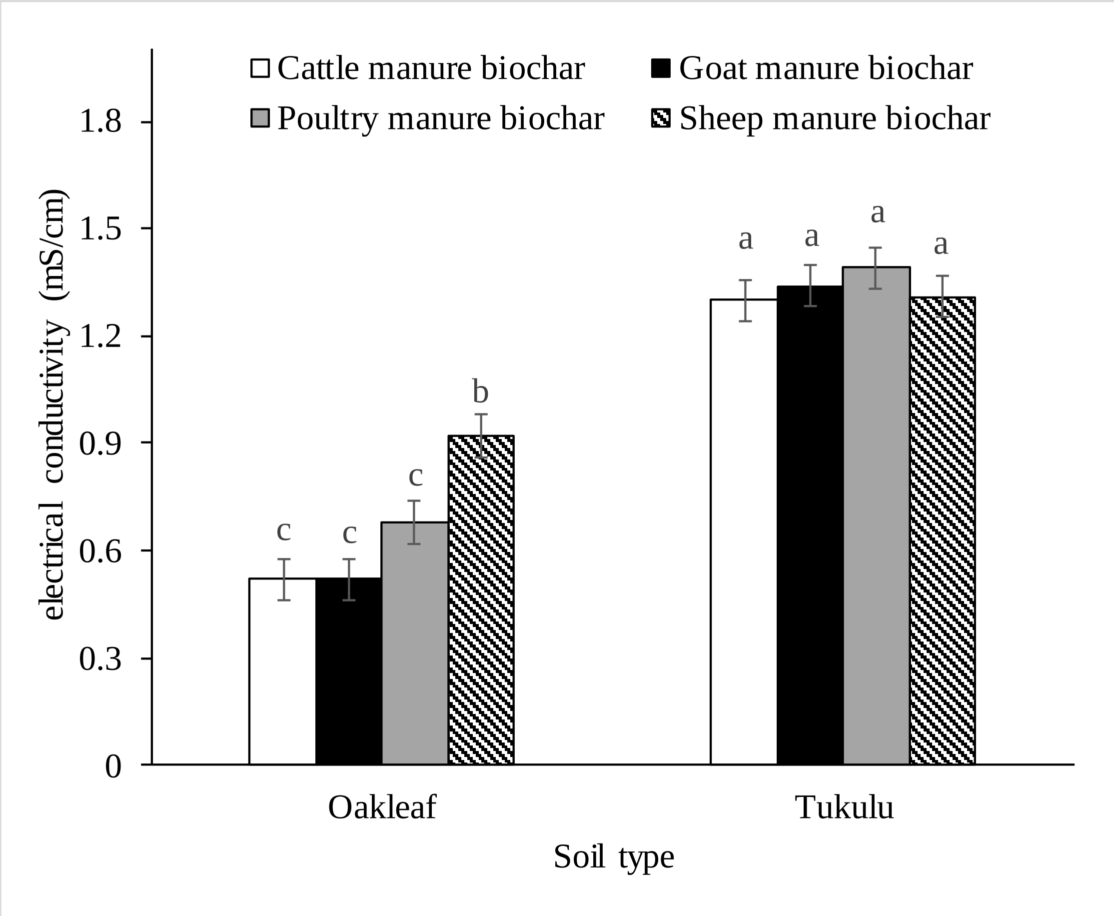


**Figure 7.3:** Interactive (Bt × St) effects on post-harvest soil electrical conductivity (mS $cm^{-1}$). Error bars denotes standard error of the mean, and different letters significant differences ($p<0.05$).

### 7.3.2. Influence of soil type, biochar type and biochar rate on maize seedling germination, growth and total biomass yield at harvest

*7.3.2.1. Effect on maize seedling germination*

Biochar type, biochar rate, soil type and their interaction had no significant ($p \geq 0.05$) effect on maize germination percentage (Table 7.5).

**Table 7.5:** ANOVA results showing maize seedling germination percentage with application of four biochar types, at five rates and, and their interactions

| Treatment | Germination (%) |
|---|---|
| Biochar type (Bt) | ns |
| Biochar rate (Br) | ns |
| Soil type (St) | ns |
| Bt × Br | ns |
| Bt × St | ns |
| Br × St | ns |
| Bt × Br × St | ns |
| CV (%) | 24.28 |

*7.3.2.2. Effect of soil type, biochar type and biochar rate on maize height and number of leaves*

ANOVA conducted on maize height for observations made from 14 DAP to 42 DAP at weekly intervals is shown in Table 7.6. Significant differences ($p \leq 0.05$) were observed on maize plant height which was determined every week. At 14 days after planting (DAP), the interaction between biochar type × soil type and between the biochar rate × soil type had significant ($p \leq 0.05$) effects on maize height. At 21 DAP and 28 DAP, interaction between biochar type × biochar rate were significant, and main effects gave significant ($p \leq 0.05$) differences on maize height. At 35 DAP, highly significant ($p \leq 0.001$) biochar rate main effects were obtained on plant height and, at 42 DAP harvest day, interactions between biochar type × biochar rate × soil type, biochar type × soil type resulted in significant ($p \leq 0.05$) differences.

**Table 7.6:** ANOVA results showing maize height and leaf number with application four biochar types, at five rates and, and their interactions

| Treatment | Sampling time (Days after planting) | | | | |
|---|---|---|---|---|---|
| **Height (cm)** | 14 DAP | 21 DAP | 28 DAP | 35 DAP | 42 DAP |
| Biochar type (Bt) | ns | ns | ns | ns | 0.008** |
| Biochar rate (Br) | ns | ns | ns | <0.0001*** | <0.0001*** |
| Soil type (St) | ns | 0.014* | 0.012* | ns | <0.0001*** |
| Bt × Br | ns | 0.004** | 0.02* | ns | ns |
| Bt × St | 0.015* | ns | ns | ns | <0.0001*** |
| Br × St | 0.013* | ns | ns | ns | ns |
| Bt × Br × St | ns | ns | ns | ns | 0.004** |
| CV (%) | 7.43 | 7.46 | 8.46 | 8.13 | 5.22 |
| **Leaf number** | | | | | |
| Biochar type (Bt) | ns | ns | ns | ns | ns |
| Biochar rate (Br) | 0.002** | ns | ns | ns | ns |
| Soil type (St) | ns | ns | ns | ns | 0.012* |
| Bt × Br | ns | ns | <0.0001*** | 0.023* | ns |
| Bt × St | ns | ns | 0.001** | ns | ns |
| Br × St | ns | ns | ns | ns | ns |
| Bt × Br × St | ns | ns | 0.002** | ns | ns |
| CV (%) | 13.71 | 11.98 | 7.30 | 8.21 | 11.35 |

Biochar rate main effects had significant ($p \leq 0.05$) effect on leaf number at 14 DAP. No significant ($p \geq 0.05$) differences were obtained at 21 DAP. At 28 DAP there were significant interactions ($p \leq 0.05$) of biochar type × biochar rate × soil type, biochar type × soil type, and biochar type × biochar rate. Interaction between biochar type × biochar rate was significant ($p \leq 0.05$) at 35 DAP whilst, at 42 DAP only soil type main effects had significant ($p \leq 0.05$) effects on number of leaves (Table 7.6).

The Bt × St interaction with respect to maize height at 14 days after planting is presented in Figure 7.4. The amendment of cattle manure biochar in an Oakleaf gave non significant differences on maize height as compared with the amendment of goat manure biochar in the Tukulu soil.

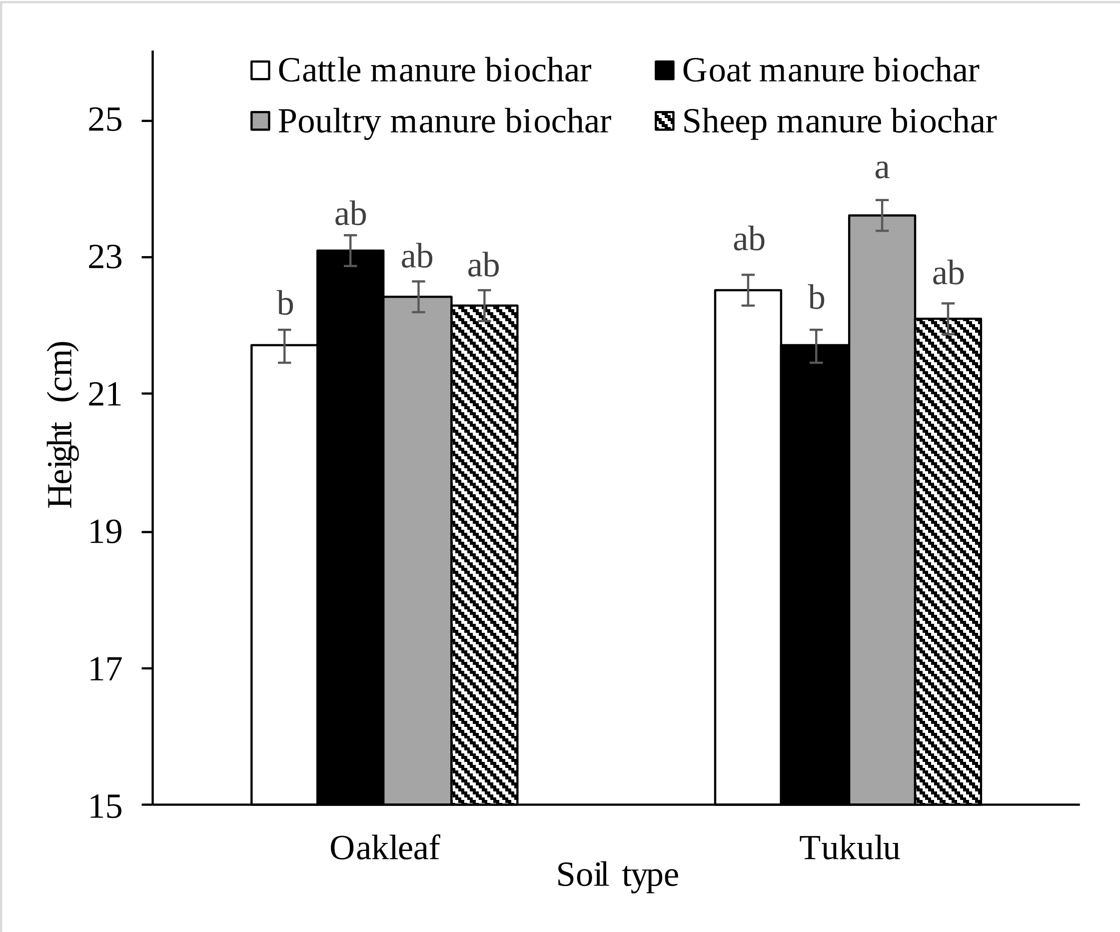


**Figure 7.4:** Interactive (Bt × St) effects on maize height (cm) determined at 14 days after planting. Error bars denotes standard error of the mean, and different letters significant differences ($p<0.05$).

Amendment with goat manure, poultry manure and sheep manure biochar in Oakleaf soil resulted in non significantly different maize heights when compared with amendment of cattle manure and sheep manure biochar amendments in a Tukulu soil (Figure 7.4).

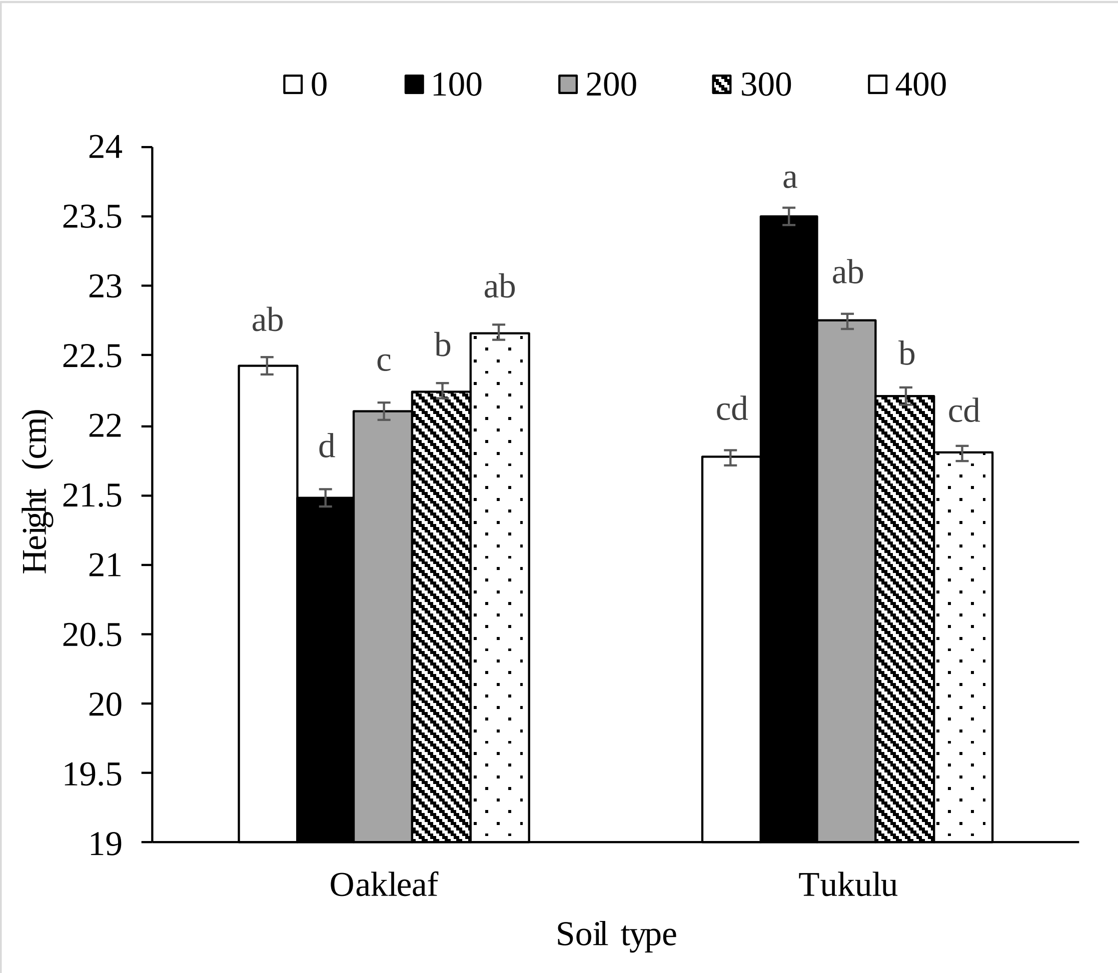


**Figure 7.5:** Interactive (Br × St) effects on maize height (cm) determined at 14 days after planting. Error bars denotes standard error of the mean, and different letters significant differences ($p<0.05$).

The Br × St interaction with respect to maize height at 14 days after planting is presented in Figure 7.5. Control in the Oakleaf soil resulted in maize heights that was significant with the rate at 100 kg C $ha^{-1}$ (Oakleaf soil), control and rate at 400 kg C $ha^{-1}$ in the Tukulu soil.

However, the results indicated that, it was not different with biochar rates at 300, 400 kg C ha$^{-1}$ (Oakleaf soil) and 100, 200, 300 kg C ha$^{-1}$ (Tukulu soil) (Figure 7.5).

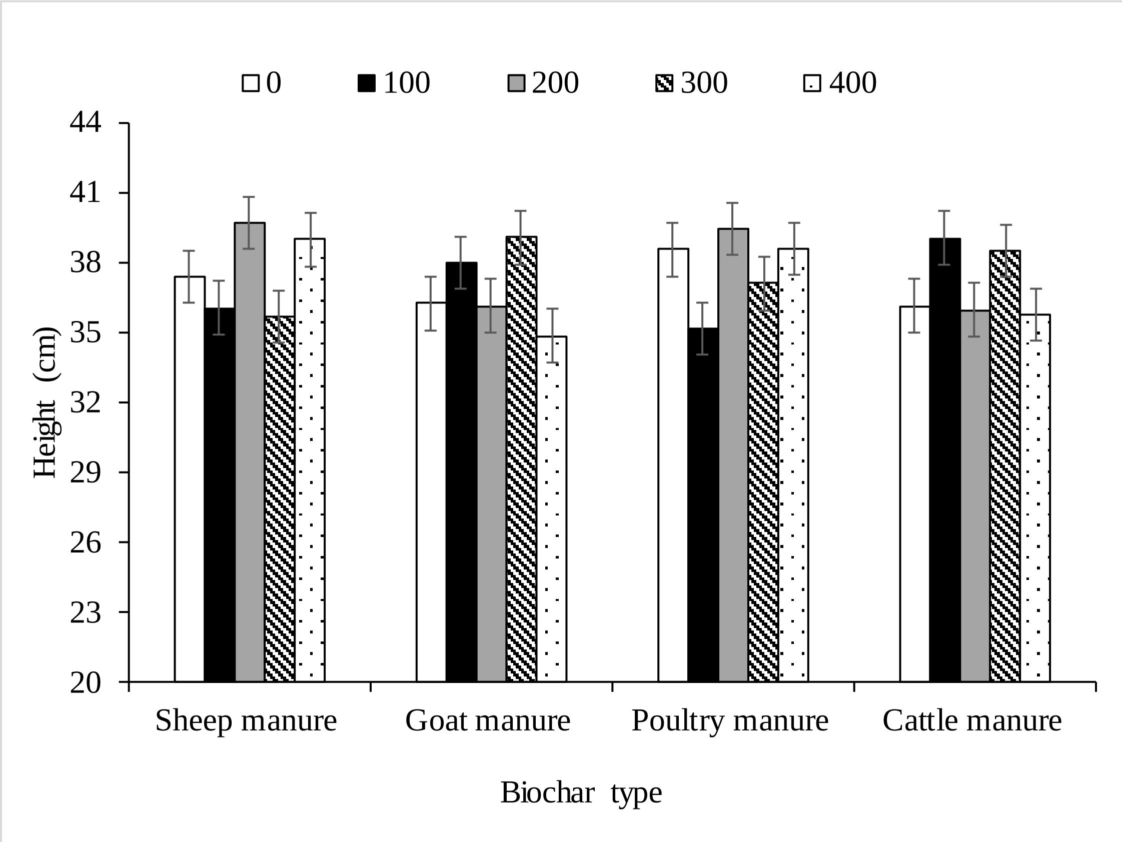


**Figure 7.6:** Interactive (Bt × Br) effects on maize height (cm) determined at 28 days after planting. Error bars denotes standard error of the mean, and different letters denote significant differences ($p<0.05$).

The Bt × Br interaction with respect to maize height at 28 days after planting is presented in Figure 7.6. Amendment of sheep manure biochar and poultry manure biochar at 200 kg C ha$^{-1}$ resulted in significantly high maize height. There were nosignificantly different when compared to the control. For instance, 400 kg C ha$^{-1}$ was for sheep manure biochar, 100 and

300 kg C ha$^{-1}$ for goat manure biochar whereas, control, 300 and 400 kg C ha$^{-1}$ was for poultry manure biochar and 300 kg C ha$^{-1}$ cattle manure biochar as shown in Figure 7.6.

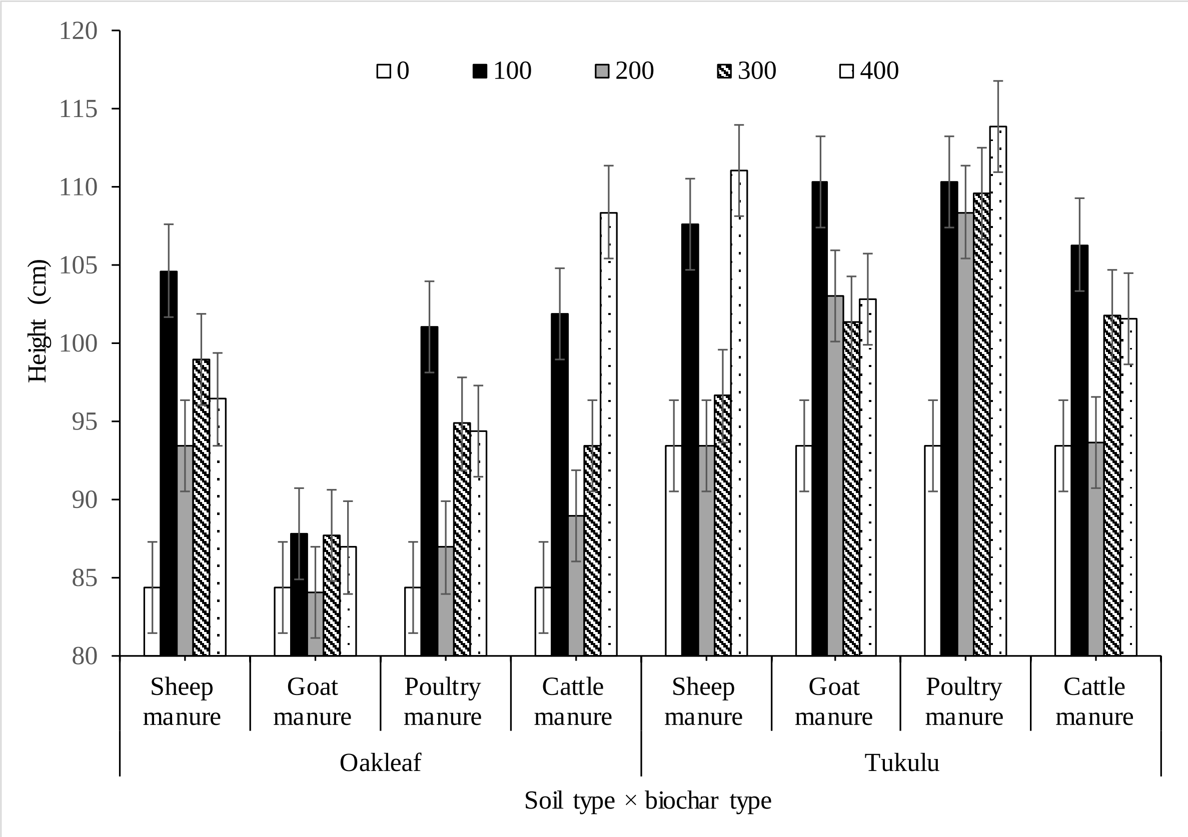


**Figure 7.7:** Interactive (Bt × Br × St) effects on maize height (cm) determined at harvest (42 days after planting). Error bars denotes standard error of the mean, and different letters significant differences ($p<0.05$).

The Bt × Br × St interaction with respect to maize height harvest is presented in Figure 7.7. Higher heights were obtained with cattle manure biochar application at 400 kg C ha$^{-1}$ and poultry manure biochar application at 400 kg C ha$^{-1}$ in the Oakleaf and Tukulu soil, respectively. Poultry manure biochar application at 400 kg C ha$^{-1}$ resulted in heights which were not significantly different with goat manure biochar application at 100 kg C ha$^{-1}$ and sheep manure biochar application at 400 kg C ha$^{-1}$ in the Tukulu soil. Cattle manure biochar application at 400 kg C ha$^{-1}$ resulted in heights which were not significant whereas, sheep manure biochar application was at 100 kg C ha$^{-1}$, and poultry manure biochar application was 300 kg C ha$^{-1}$ in the Tukulu soil (Figure 7.7).

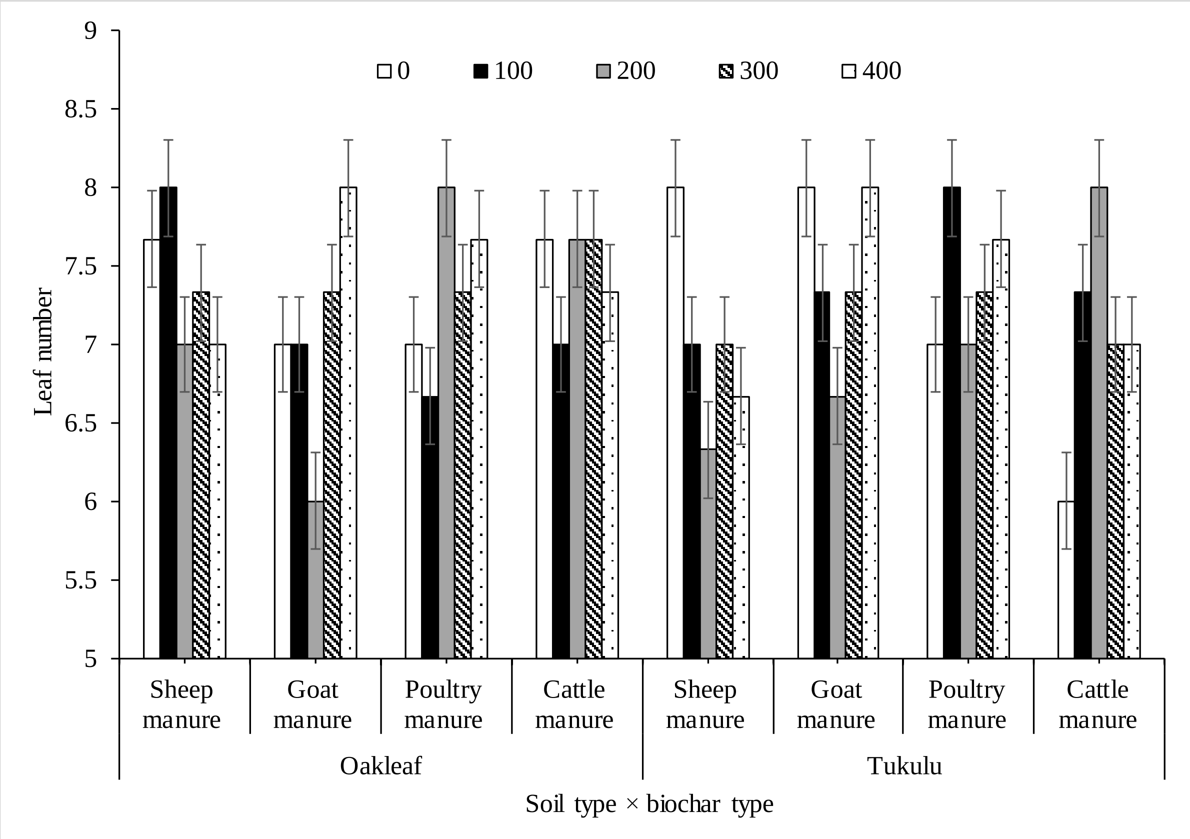


**Figure 7.8:** Interactive (Bt × Br × St) effects on maize leaf number determined at 28 days after planting. Error bars denotes standard error of the mean ($p<0.05$).

The Bt × Br × St interaction with respect to maize height harvest is presented in Figure 7.8. the highest number of leaves were in both Oakleaf and Tukulu soils. The application of cattle, goat, and poultry manure biochar application at 200, 400, 200 kg C ha$^{-1}$ in the Tukulu soil did not result in significantly different number of leaves with the application of poultry manure biochar (200 kg C ha$^{-1}$), sheep manure biochar (100 kg C ha$^{-1}$), and goat manure biochar (400 kg C ha$^{-1}$) in the Oakleaf (Figure 7.8).

*7.3.2.3. Effect of soil type, biochar type and biochar rate on maize total biomass yield at harvest*

Three-way and two-way interactions of biochar type, biochar rate and soil type were not significant ($p \geq 0.05$). Only the main effects of biochar rate had a significant ($p \leq 0.05$) effect on biomass yield at harvest (Figure 7.9).

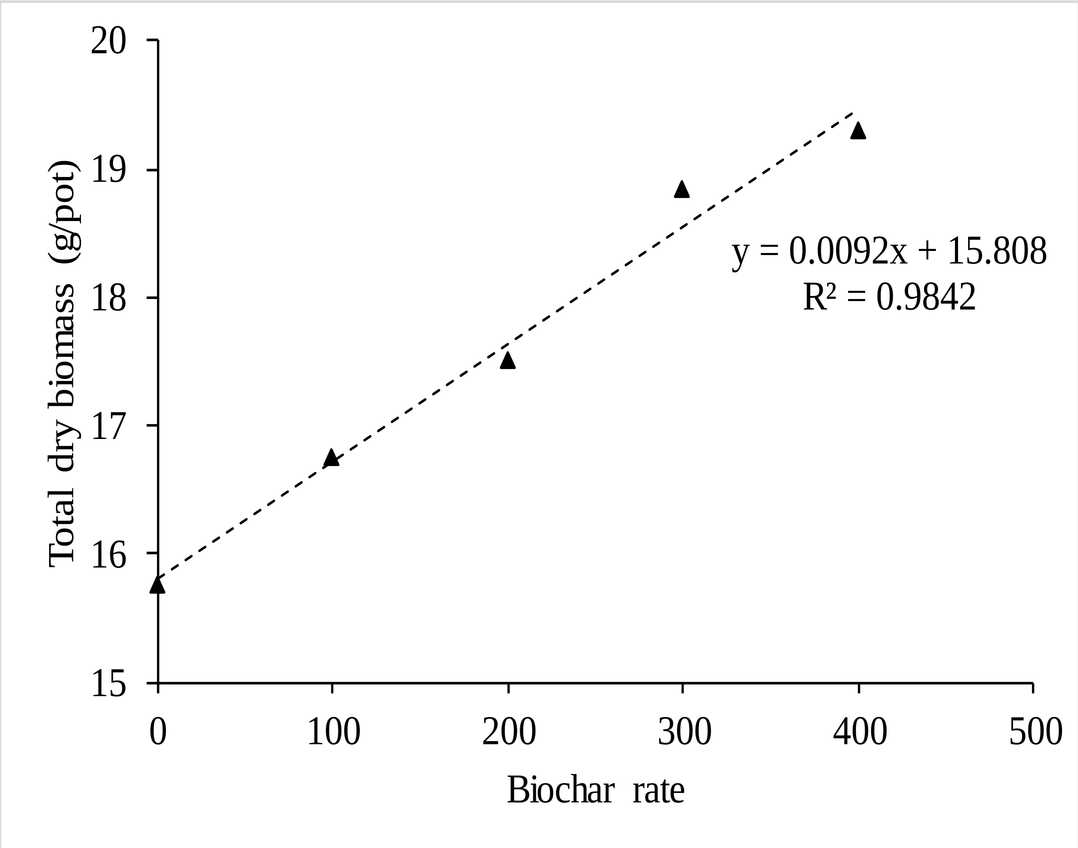


**Figure 7.9:** Comparison of maize total dry biomass with biochar application rate

The biomass yield ranged from 14.77 g $pot^{-1}$ to 20.31 g $pot^{-1}$ and only the control (0 kg C $ha^{-1}$) and the biochar application at 400 kg C $ha^{-1}$ had significantly different biomass yields (Figure 7.9).

## 7.4. Discussions

### 7.4.1. Effects of biochar type and rate on post-harvest soil chemical properties

Soil properties are reported to be improved with biochar application, but are not always consistent. The addition of biochar to agricultural soil is usually intended to improve soil properties so as to increase crop yields and, there is evidence that this may be successful with positive results from earlier studies (Schulz *et al*., 2013; Glaser *et al*., 2002; Rondon *et al*., 2007; Chan *et al*., 2008; Cornelissen *et al*., 2013). The results of the study showed that biochar type and the rate of biochar application influenced soil chemical properties during harvesting period (42 days). An increase in the rate of biochar application from 100 to 400 kg C $ha^{-1}$ increased the pH of the soil. Moreover, it was observed that, increases were more pronounced in the Oakleaf soil which had an acidic pH, than it was in the Tukulu soil which had a higher pH. Addition of biochar effect on pH was observed for acidic soils (Novak *et al*., 2009; Laird *et a*l., 2009) and this was also found in Chapter 5 of this study.

Application of biochar to acid sandy soils were reported to increase crop yields (Glaser *et al*., 2002), whereas addition of biochar to clayey soil does not always increase the crop yields (Cornelissen *et al*., 2013). Electrical conductivity in this study also increased with biochar type and application rate in both soil types. The ash content of biochar is responsible for the EC changes and can have an influence of crop growth if biochars with high salt concentration are used (Chan *et al*., 2008). Positive increases in Olsen P were also observed in the study were P concentrations were improved in post-harvest.  The improvement were noticed to be increasing biochar rate of applications. The results can be related to improved plant growth and dry biomass yields obtained because of improvements in soil nutrient as previously reported by earlier studies (Lehmann *et al*., 2003).

### 7.4.2. Effects of soil type, biochar type and application rate on maize seedling growth

Although the findings of the study show that no significant differences on maize growth were obtained with biochar type main effects. Application of biochars at different rates resulted in significant ($p \leq 0.05$) differences on maize growth at 14 days after planting on the number of leaves and 35 and 42 days after planting on the height. Therefore, the results suggested that, application rate treatment can be effectively used in optimising biochar application for recommending biochar adoption. The results of the study align with  earlier studies that biochar would bring differences at different application rates. Generally, it is reported that improved growth and yield are easily distinguished when biochar is applied at different rates combination with inorganic fertilizer (Rajkovich *et al*., 2012).

Uzoma *et al*. (2011) also reported significantly improved maize yields by application of cow manure biochar at 20 t $ha^{-1}$ in a greenhouse experiment. It may be impied that, it is quite early to observe significant differences on growth in the first season with biochar treatment. A study by Major *et al*. (2010) indicated that, no change in maize yield in the first year were obtained but, significant increases were obtained in the next three years with wood biochar application at 20 t $ha^{-1}$. The nutrient contents of the biochars were generally comparable to that of the manure, except of N which volatilizes during pyrolysis. In a separate comparative study, an investigating on cattle manure and its biochar at an equivalent single application rate of 20 t $ha^{-1}$, with and without combination of inorganic fertilization was conducted by Uzoma *et al*. (2011). The results revealed that, biochar only treatments had non-significant differences with control treatments, but non-significant differences were also obtained in biochar combined with fertilizer and fertilizer and manure treatments (Chapter 6). This might be another possible explanation to slow growth in biochar application at low rates in this study during the early growth stages of maize.

The high biomass yield attained from application rate at 400 kg C $ha^{-1}$ indicates the increased nutrient supply and improved fertilizer use efficiency of biochar. Low biomass attained in the control (0 kg C $ha^{-1}$) and at low (100, 200 and 300 kg C $ha^{-1}$) application rates further confirms the notion that indeed, biochar can have differences on growth depending on the rate of application. In consistence with previous studies, poultry litter biochar and cattle manure biochar were reported to have high levels of N and P that can be used as slow release fertilizers (Chan *et al*., 2008; Dai *et al*., 2015). In addition, Blackwell *et al*. (2010) reported a significant increase in dry matter wheat production with biochar application in combination with inorganic fertilizer. The low biomass attained in the control further confirms that the soils used for this study were inherently infertile. Application of biochars combined with fertilizer subsequently increased the biomass yield amongst the different application rates. The findings of the study corroborate with earlier results showing that a combination of biochar with inorganic fertilizers enhances soil fertility on degraded soils, and improves crop performance compared to unamended (no biochar) control treatments (Kimetu *et al*., 2008).

## 7.5 Conclusion and recommendations

The study has confirmed that soil amendment with biochar of different types and rate of application results in improved soil pH, electrical conductivity and Olsen P of an Oakleaf soil and improvements were negligible in the Tukulu. Sheep manure biochar was better at ameriolating pH, electrical conductivity and Olsen P in both soils. Application of biochars at higher rates was observed to result in maize biomass improvements. For instance, maize growth was promoted in treatments with the highest rate of biochar application (400 kg C $ha^{-1}$). Goat manure biochar (GMB) performed outstandingly as compared to other biochar types that were used in the study. Therefore, more research is needed to find out biomass improvement with alternate biochar feedstock.

# 8. GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

## 8.1. Motivation and objective of the study

Low soil organic carbon is suspected to be the major reason why low fertilizer input farming systems in the Eastern Cape (EC) lead to problems with yields harvested by smallholder farmers (Mandiringana *et al*., 2005). It was hypothesized in this study, that transformation of livestock manures into more stable carbon form "biochar" and application into carbon degraded soils could result in realization of soil fertility benefits and improve crop yield. The aim of this study was to quantify the benefits of biochar produced from cattle, goat, sheep and poultry manure to soil fertility and growth of maize seedlings in order to provide a scientific basis for making recommendations.

This chapter brings together the findings from Chapters 3 – 7 to address the specific objectives listed in Chapter 1, especially Objective 3 which was meant to identify feedstock availability and utilization so as to motivate for alternative biochar production. Livestock manure production in the Raymond Mhlaba Municipality was estimated to be in huge amounts. This is because evaluation of the proportion of farmers utilizing the manure and application rates utilized suggested that the resource would be somehow underutilized. Motivation for alternative biochar production was the rapid soil mineralization of fresh organic amendments (manures) and frequent labour requirement of soil application to maintain soil fertility (Calderon *et al*., 2015).

Objective 4 was addressed the influence of the pyrolysis process of livestock manures feedstock and to compare the biochar properties with their feedstock properties so as to assess the potential of converting livestock manures to biochar in soil fertility management. The aim of this study was to further assess the influence of feedstock characteristics, on the C content, nutrient content and release, and soil C sequestration of amendment as highlighted in Chapters 5, 6, and 7. This was done to promote and motivate its adoption for soil carbon sequestration and fertility management. Furthermore, this dissertation considered the trade-off of converting livestock manure into biochar. In addition, investigating comparative effects of these amendment on maize seedling growth using soil samples collected from farmers' fields in cultivation and abandoned maize fields was dicussed in Chapter 6. The use of a set of biochars at different application rates, as opposed to a single biochar type and single rate of application, is useful to effectively identify and explain relationships between biochar type and rate of application on soil chemical properties and maize seedling growth (Chapter 7). This could be then be used to formulate customized recommendations for biochar application to farmers.

## 8.2. General discussion of findings

### 8.2.1. Farming system, availability and utilization of manure

Household surveys showed that livestock husbandry was the main source of livehood whereas, crop production as a livelihood source was negligible. The majority of the households were having smallholdings of arable land which was not in use. Subsistence cropping commonly involved maize by a small proportion of the farmers. The minority of the farmers utilized livestock manures to manage soil fertility opposing earlier studies by van Averbeke *et al*. (2008) and Mkile (2001) who found the majority of household utilizing manures in cropping. This study showed that, the situation has changed and a smaller proportion of farmers were involved in cropping and even a smaller proportion utilized manure for soil fertility management with application rates between 500 kg – 1200 kg. Hence, it was evident that the amounts of manure that are available at farmers households are not enough for recommended application rates an indication that, there is need to find ways to maximize the value of the small manure quantities available and encourage their utilization in cropping. If the farmers were to apply manures at recommended application rates that are higher than 10 t $ha^{-1}$ (Yoganathan *et al*., 1998) then, the manure resources would not be enough.

8.2.2. Production and characteristics of biochar from manures

Slow pyrolysis method of biochar production with cattle, goat, sheep, and poultry manures as feedstock materials was used because of its simplicity in adoption and relatively higher biochar outputs (Duku *et al*., 2011). The biochars were produced at pyrolysis temperature of 400$^{o}$C and produced yields above 50%. The results of proximate analysis (fixed C) and nutrient analysis have extensively been used to assess the C stability of biochar as a soil amendment. The results of this study aligned with studies by (Chan *et al*., 2008; Dai *et al*., 2015, Wang *et al*., 2015) which showed that pH, EC, and nutrient composition of the biochars were higher as compared to the feedstocks.

However, the emerging results do not give a good indication of the treatment conditions biochar could go through once applied to soil. In Chapter 4, the feedstock manure was deemed to influence the final biochar properties, and exhibited an impact on the measurement of biochar ash content, fixed C yield and nutrient concentration. The highest fixed C yields were seen for biochar produced from cattle manure and sheep manure. The lower fixed C yields of the biochars could be the result of labile C fractions and larger concentration of ash (Cely *et al*., 2014). The pH of the biochar was increased in comparison to that of the manures with pyrolysis, due to the release of acidic volatile material (Chan and Xu, 2009). An alkaline pH in biochar can cause a liming effect within soil leading to improvements in soil fertility. Feedstock manure was deemed to be the determining factor in the biochar nutrient concentration since biochar nutrients are mainly located within the feedstock ash (Touray *et al*., 2015).

In summary, pyrolysis of manure feedstocks has clearly shown an improvement in the chemical properties of the biochar and C sequestration potential. This can lead to  which can inclusion of biochar as an alternative C sequestration and soil fertility improvement amendment. It should be noted that assessment of biochar characteristics should not be sorely used to make such recommendations.

8.2.3. Soil dynamics, carbon and available nitrogen and phosphorus nutrient release

Due to low temperature in slow pyrolysis, biochars produced may contain unconverted or partially converted biomass fractions, known as labile C, which upon soil amendment is rapidly mineralized. Although, long term biochar nutrient release is vital to understanding the C sequestration potential of the fixed C fractions, it is pivotal to evaluate the short term nutrient release of biochar to assess how the labile C fraction of biochar which can be rapidly mineralized. Moreover, it is important to note that soil-biochar nutrient release studies at field level are easily affected by environmental conditions, and the required experimental conditions are difficult to create or control. Therefore, in this study, a laboratory incubation experiment was carried out to evaluate the effects of biochar type on soil organic carbon (SOC) available N and P associated with livestock manure biochar amendments.

The results of Chapter 4 confirmed the significant influence that pyrolysis livestock manures improved the nutrient concentration in the biochar. In addition, biochar soil amendment have been reported to cause the priming of SOM over short periods of time (Zimmerman *et al*., 2011). The results emerging from this study indicated that soil biochar treatment at 2 % C resulted in significantly higher SOC content but no significant fluctuations were obtained with incubation time. The findings of the study further signified the recalcitrant nature of biochar. Small fluctuations were observed and might point out to the partially uncovered labile C fractions in the biochar. Priming of SOM with biochar was reported to be negligible in many cases due to the loss of native SOM being smaller than the C gained following biochar application to soil (Woolf and Lehmann, 2012; Zornoza *et al*., 2016; Darby *et al*., 2016). However, the mineralization of biochar either in short or long term basis in the environment may be found to be lower under laboratory conditions because of less favorable treatment conditions.

8.2.4. Comparative effect of cattle manure and its biochar amendment in a degraded Hutton soil of differing cultivation history on maize seedling growth

Biochar's agronomic significance is poorly understood due to the inability to predict its impact in soil due to the difficulty in reproducibility of biochar properties (Shackley *et al*., 2011). Before recommending large-scale application of biochar at fields, it is pivotal to assess the positive and negative effects of biochar using pot experiments where conditions are controlled. Therefore, analysing agronomic characteristics of biochar samples with crop growth and incubation to determine nutrient release patterns as seen in Chapter 4 and 5, enabled the prediction of biochar properties and its performance as a function of crop growth and soil properties.

In this study, comparisons of maize growth in a Hutton soil from cultivated and abandoned soil with amendments of cattle manure feedstock and biochar combined inorganic fertilizer treatment were also studied. This was done in order test the benefits of converting cattle manure and applying it to the soil rather than just applying it without altering. In both cultivation histories, manure increased growth of maize, whilst the biochar showed no differences with the control. In some instances, amendment even performed better in the abandoned soil as compared to the cultivated soil. This suggests possible soil fertility recovery in abandoned soil with the use of amendment. In addition, a loss in terms of maize growth performance when livestock manure is converted to biochar is relative as compared to utilizing it in its state. It could also be deduced from the finding of the study that, there were improvements when the biochar was incorporated with inorganic fertilizer. The results further imply that biochar benefits on crop growth are difficult to obtain within a short period of time. Results are in support with earlier studies conducted by Uzoma *et al*. (2011), and Calderon *et al*. (2015) who observed that biochar treatment could not improve growth of crops.

8.2.5. Effect of soil type, manure biochar type, and application rate on growth of maize seedlings and soil chemical properties

Biochar application rate has a pronounced effect on maize growth and total dry biomass yield. The quantity of carbon application were higher application rates (400 kg C $ha^{-1}$) were used showed superior growth and biomass yield performance to 200 kg C $ha^{-1}$. This study was relevant, because soils of low SOC were utilized. Therefore, information was available for the comparison of effects of biochar on two contrasting soils. Thus, where feedstock availability is limited especially on smallholder farmers' households, low application rates can be used with inorganic fertilizer application to improve maize growth and biomass yield. Moreover, the results highlighted that the choice of manure biochar type has limited influence on maize growth and biomass yield.

**8.3. Relevance and limitations of findings**

The findings of this study are relevant to the development of long-term soil fertility management strategies. Management of soil fertility has been a great challenge to smallholders in South Africa, Eastern Cape Province because of the fast paced continued soil degradation. This has been due to several natural factors and inappropriate agronomic and management practices. It is vital to note that natural factors are inevitable so they cannot be altered, thus research aims to make agriculture sustainable with regard to such scenarios. In addition,  adverse effects of natural influences can be minimised or ameliorated through sustainable management practices. In South African soils, N and P are the most limiting soil nutrient for crop yields as well as low SOC levels exposed the soils to erosion and further degradation (Mandiringana *et al*., 2005). In mixed farming systems of smallholder farmers poor, agronomic management, especially for soil fertility management play a major role in reducing crop yields. Research findings of this study indicated that the application of biochar is beneficial for soil carbon sequestration, soil fertility and crop growth. Biochar application under controlled conditions has also proven to be beneficial over none use of biochar. As a carbon sequestering material, biochar can also be used to manage carbon in degraded soils.

This study recognizes some issues that should be considered in future research. The sample size used in the survey is not large enough to draw up a conclusion to limited manure utilization in the Raymond Mhlaba Municipality. The production method used in preparing biochar should have utilized a range of pyrolysis temperatures. The number of days used for soil incubation period was 46, and this might be a problem taking into consideration that biochar is subjected to oxidation (Cheng *et al*., 2006) and ageing reactions (Brewer *et al*., 2011). Therefore, based on these assumptions, the results can only be interpreted as short-term effects of biochar on soil properties. Furthermore, the pot experiments of this study had limitations during observations for maize growth and development. However, the maize yield after full growth and development is equally important. This is a concern which needs consideration since biochar influence on soil properties may not be fully noticeable and this may impact crop growth.

## 8.5. Conclusions

The findings of this study have advanced the understanding of some basic aspects of the biochar-soil and biochar-soil-crop interactions on soil fertility and crop productivity with biochar produced from livestock kraal manures. The major objectives were summarized in the discussion section and the results of this study conclude that:

(i) Livestock kraal manure is an important potential feedstock material for biochar production in the EC since its availability in most households was rich. The survey established low utilization of manure in cropping and if motivated properly, biochar can be an option to encourage smallholder farmers to revive crop production.

(ii) Biochars originating from livestock kraal manures vary significantly in chemical and physical properties. This impies that characterization is essential for soil fertility applicability. Therefore, recommendations should only be drawn based upon these characteristics. Biochars evaluated in this study had high nutritional composition when compared to their feedstock manures, signifying higher potential for adoption.

(iii) The soil C, available N, and P were significantly increased with biochar amendments. Although, this finding neither showed a clear increase nor a clear decreasing influence of biochar on organic carbon, available N especially ammonium concentrations were increased with time. However, Olsen P release was not consistent and clear with increasing time, this indicated that with biochar amendments over time, soil fertility can be realized.

(iv) Amending biochar combined with fertilizer in the soil sampled from abandoned farmers' fields showed improved maize growth and yield when as compared to soil that was sampled from farmers' fields in cultivation. The findings from the study proved that indeed biochar has some remedial soil fertility properties. However, low biomass yield which was not significantly different from the control was obtained from biochar only treatments, signaling the notion that biochar is not a fertilizer. Hence, the biomass increase can be explained as a synergy of the effects of biochar on the nutrient concentrations supplied with fertilizer application, which are further increased by the porous structure capacity of biochar to act as a nutrient holder and medium for microorganisms.

(v) The effects of biochar on soil nutrients redistribution emerged when biochars were applied at 5 application rates. Rate of biochar application at 400 kg C $ha^{-1}$ was comparable to 200 C $ha^{-1}$ in the Tukulu soil than it was in the Oakleaf soil. These findings showed that higher application rates can only work effectively in degraded soil.

## 8.6. Recommendations

The studies were constrained by the time frame of a masters' dissertation and lack of field experiments was a limit to these findings. There are a number of research areas on the influence of biochar application in SOC depleted soils that still require investigation. This study might have set down initial groundwork to refine the biochar production from locally available feedstock materials, influence on soil fertility, crop productivity and thus, any future research should be focuse on the following topics:

(i) Explore the agronomic response of biochars produced from an array of feedstock materials locally available at farmers' households and their ability to address key soil constraints under different environmental (field) conditions (soil type, climate conditions, management). To be able to track changes in the physical and chemical properties of the biochar-amended soils, improvements or gains in crop yields in long-term studies.

(ii) Increasing the scale of pyrolysis from small-scale to industrial-scale would influence the agronomic and economic feasibility of biochar production. Thus, potential for biochar production should be tailored towards improvement of specific soil constraints in selected locations.

(iii) Implementing and conducting a research into the soil-biochar interactions on maize growth considered in this study at PhD level under field conditions, in order to understand more realistic situations, which are far more complex than incubation and glasshouse studies. Long-term field studies are crucial for exploring the mechanisms which lead to improved crop production across a wide range of agricultural conditions. The studies should also focus on the duration of these positive impacts as biochar ages, and regional differences that soil type and climate may have on biochar's environmental response.

# REFERENCES

Abbasi MK, Anwar AA. 2015. Ameliorating Effects of Biochar Derived from Poultry Manure and White Clover Residues on Soil Nutrient Status and Plant Growth Promotion - Greenhouse Experiments. *Plos One*. 10(6):131-592.

Abebe A, 2015. Production and reproduction performances of livestock and their implication on livestock water productivity in mixed crop-livestock systems in the highlands of Blue Nile basin: A case study from Fogera, Diga and Jeldu districts (Ethiopia). *Journal of Rresources Development and Management*, 10: 2422-8397

Adediran JA, De Baets N, Mnkeni PNS, Kiekens L, Muyima NYO, Thys A. 2003. Organic waste materials for soil fertility improvement in the border region of the Eastern Cape, South Africa. *Biological Agriculture & Horticulture*, *20*(4): 283-300.

Agri Laboratory Association of Southern Africa (AgriLASA). 2004. Soil Handbook. Pretoria (South Africa): Agri Laboratory Association of Southern Africa. Pretoria, South Africa.

Alburquerque JA, Calero JM, Barrón V, Torrent J, Carmen M, Gallardo A, Villar R. 2014. Effects of biochars produced from different feedstocks on soil properties and sunflower growth. *Journal of Plant Nutrition and Soil Science,* 177: 16–25.

Ali H, Descheemaeker K, Steenhuis T, Pandey S. 2011. Comparison of Land use & Land Cover Changes, Drivers and Impacts for a Moisture-Sufficient and Drought-Prone Region in the Ethiopian Highlands. *Experimental Agriculture*, 47: 71-83.

American society for testing and materials (ASTM). 2011. ASTM D2866-11: Standard test method for total ash content of activated carbon; ASTM: West Conshohocken, PA, USA.

American society for testing and materials (ASTM). 2014. ASTM D2867-09: Standard test methods for moisture in activated carbon; ASTM: West Conshohocken, PA, USA.

American society for testing and materials (ASTM). 2014. ASTM D5832-98: Standard test method for volatile matter content of activated carbon; ASTM: West Conshohocken, PA, USA.

Amonette JE, Joseph S. 2009. Characteristics of biochar: Microchemical properties. In Lehmann J and Joseph S (eds), *Biochar for Environmental Management*, ch. 3. London: Earthscan Publishers.

Arthur E, Tuller M, Moldrup P, de Jonge LW. 2015. Effects of biochar and manure amendments on water vapor sorption in a sandy loam soil. *Geoderma*, 243: (244) 175–182.

Bai SH, Xu CY, Xu ZH, Blumfield TJ, Wallace HM, Walton DA, Randal BW, Van Zwieten L. 2016. Wood base biochar alters inorganic N. *Acta Horticulture (ISHS)*, 1109: 151-154.

Baiphethi MN, Jacobs PT. 2009. The contribution of subsistence farming to food security in South Africa. HSRC 31 December 2009, Pretoria.

Basso AS, Miguez FE, Laird DA, Horton R, Westgate M. 2013. Assessing potential of biochar for increasing water-holding capacity of sandy soils. *GCB Bioenergy,* 5 (2): 132–143.

Bembridge TJ. 1984. A systems approach study of agricultural development problems in Transkei. PhD Thesis, University of Stellenbosch, South Africa.

Bester J, Ramsay KA, Scholtz MM. 2009. Goat farming in South Africa: Findings of a national livestock survey. *Applied Animal Husbandry and Rural Development*, 2: 9–13.

Blackwell P, Krull E, Butler G, Herbert A, Solaiman Z. 2010. Effect of banded biochar on dry land wheat production and fertiliser use in south-western Australia: An agronomic and economic perspective. *Australian Journal of Soil Research*, 48: 531–545.

Blackwell P, Krull E, Butler G, Herbert A, Solaiman Z. 2010. Effect of banded biochar on dry land wheat production and fertiliser use in south-western Australia: An agronomic and economic perspective. *Australian Journal of Soil Research*, 48: 531–545.

Brady NC, Weil RR. 2012. The nature and properties of soils. Revised fourteenth ed. Dorling Kindersley (India) Pvt. Ltd., New Delhi 110017, India

Brewer CE, Chuang VJ, Masiello CA, Gonnermann H, Gao X, Dugan B, Driver LE, Panzacchi P, Zygourakis K, Davies CA. 2014. New approaches to measuring biochar density and porosity. *Biomass Bioenergy,* 66: 176–185.

Brewer CE, Hu Y, Schmidt-Rohr K, Loynachan, TE, Laird DA, Brown RC. 2011. Extent of pyrolysis impacts on fast pyrolysis biochar properties. *Journal of Environmental Quality*, 10: 234-251.

Calderón, FJ, Benjamin, J, Vigil, MF. 2015. A Comparison of Corn (Zea mays L.) Residue and Its Biochar on Soil C and Plant Growth. *Plos One*, 10 (4), e0121006.

Cantrell KB, Hunt PG, Uchimiya M, Novak JM, Ro, KS. 2012. Impact of pyrolysis temperature and manure source on physicochemical characteristics of biochar. *Bioresource Technology*, 107: 419–428.

Cantrell KB, Ro K, Mahajan D, Anjom M, Hunt PG. 2007. Role of thermochemical conversion in livestock waste-to-energy treatments: Obstacles and opportunities. *Industrial and Engineering Chemistry Research*, 46: 8918-8927.

Cayuela ML, Sanchez-Monedero MA, Roig A, Hanley K, Enders A, Lehmann J. 2013. Biochar and denitrification in soils: when, how much and why does biochar reduce N2O emissions? *Scientific Reports*, 3: 1732.

Cely P, Tarquis AM, Paz-Ferreiro J, Méndez A, Gascó G. 2014. Factors driving the carbon mineralization priming effect in a sandy loam soil amended with different types of biochar. *Solid Earth*, 5:585–594.

Cook RJ, Weller DM. 2004, September. In defense of crop monoculture. In *Proceedings of the 4th international crop science Congress* (Vol. 26, pp. 1-11).

Chan KY, Van Zwiete L, Meazaros I, Downie A, Joseph S. 2008. Poultry litter biochars as a soil amendment. *Australian Journal of Soil Research*, 46: 437–444.

Chan KY, Xu ZH. 2009. Nutrient properties and their enhancement. In: Lehmann J, Joseph S (eds) Biochar for environmental management: science and technology. Earthscan, London, pp 67–84

Cheng CH, Lehmann J, Engelhard MH. 2008. Natural oxidation of black carbon in soils: changes in molecular form and surface charge along a climosequence. *Geochimica Et Cosmochimica Acta*, 72(6): 1598-1610.

Cheng CH, Lehmann J, Thies JE, Burton SD, Engelhard MH, 2006. Oxidation of black carbon by biotic and abiotic processes. *Organic Geochemistry*, 37: 1477-1488.

Chimonyo M, Kusina NT, Hamudikuwanda H, Nyoni O. 1999. A survey on land use and usage of cattle for draught in smallholder farming area of Zimbabwe. *Journal of Applied Science*, 5: 111-121.

Chintala R, Mollinedo J, Schumacher TE, Malo DD, Julson JL. 2014. Effect of biochar on chemical properties of acidic soil. *Archives of Agronomy and Soil Science*, 60(3):393–404.

Christel W, Bruun S, Magid J, Jensen LS. 2014. Phosphorus availability from the solid fraction of pig slurry is altered by composting or thermal treatment. *Bioresource Technology*, 169: 543–551.

Clough TJ, Condron LM, Kammann C, Müller C. 2013. A review of biochar and soil nitrogen dynamics. *Agronomy Journal*, 3:275–293

Cornelissen G, Martinsen V, Shitumbanuma V, Alling V, Breedveld G, Rutherford D, Sparrevik M, Hale S, Obia A, Mulder J. 2013. Biochar Effect on Maize Yield and Soil Characteristics in Five Conservation Farming Sites in Zambia. *Agronomy*, 3 (2): 256–274.

Dai LC, Tan FR, Wu B, He MX, Wang WG, Tang XY, Hu QC, Zhang M. 2015. Immobilization of phosphorus in cow manure during hydrothermal carbonization. *Journal of Environmental Management*, 157: 49-53

Darby I, Xu C-Y, Wallace HM, Joseph S, Pace B, Bai SH. 2016. Short-term dynamics of carbon and nitrogen using compost, compost biochar mixture and organo-mineral biochar. *Environmental Science and Pollution Research*, 23: 11267–11278

DeLuca TH, Mackenzie MD, Gundale MJ. 2009. In:Lehmann J, Joseph S. (Eds) Biochar effects on soil nutrient transformations. Biochar for environmental management: Science and technology, pp 251-270

Descheemaeker K, Amede T, Haileslassie A. 2010. Improving Water Productivity in Mixed Crop-Livestock Farming Systems of Sub-Saharan Africa. *Agricultural Water Management*, 97:579-586.

Dempster DN, Gleeson DB, Solaiman ZM, Jones DL, Murphy DV. 2012. Decreased soilmicrobial biomass and nitrogen mineralisation with Eucalyptus biochar addition to a coarse textured soil. *Plant and Soil*, 354: 311–324.

Duku MH, Gu S, Hagan EB. 2011. Biochar production potential in Ghana - A review. *Renewable and Sustainable Energy Reviews*, 15: 3539–3551.

Du Preez CC, van Huyssteen CW, Mnkeni PNS. 2011. Land use and soil organic matter in South Africa: 1. A review of spatial variability and the influence of rangeland stock production. *South African Journal of Science* [Online] 107 (5 /6): 27-34.

Enders A, Hanley K, Whitman T, Joseph S, and Lehmann J. 2012. Characterization of biochars to evaluate recalcitrance and agronomic performance. *Bioresource Technology*, 114: 644–653.

Fanadzo M, Chiduza C, Mnkeni PNS, Van Der Stoep I, Steven J. 2010. Crop production management practices as a cause for low water productivity at Zanyokwe Irrigation Scheme. *Water SA*, 36(1): 27–36.

Fanadzo M. 2009. Improving productivity of maize based smallholder irrigated cropping systems: A case study for Zanyokwe irrigation scheme, Eastern Cape, South Africa. PhD Thesis. University of Fort Hare, South Africa.

FAO. 2016. www.fao.org/ag/againfo/programmes/en/lead/toolbox/Mixed1/TLU.tm. (Accessed on 18 August 2016).

FAO. 1994. Water quality for agriculture. http://www.fao.org/DOCReP/003/T0234e/T0234E00.htm#TOC (Accessed August 2016).

Fischer D, Glaser B. 2012. Synergisms between compost and biochar for sustainable soil amelioration. *Management of Organic Waste,* 10: 167–198

Fraiser G, Monde N, Van Averbeke W. 2003. Food security in South Africa: A case study of rural livelihoods in the Eastern Cape. In Nieuwoudt, L. & Groenewald, J (Eds). The challenge of change: Agriculture, land and the South African economy. University of Natal Press, Pietermaritzburg.

Free HF, McGill CR, Rowarth JS, Hedley MJ. 2010. The effect of biochars on maize (Zea mays) germination, *New Zealand Journal of Agricultural Research*, 53(1): 1-4

Fujita I, Tomooka J, Sugimura T. 1991. Sorption of anionic surfactants with wood charcoal. *Bulletin of the Chemistry Society of Japan*, 64:738–740.

Gascó G, Cely P, Paz-Ferreiro J, Plaza C, Méndez A. 2016. Relation between biochar properties and effects on seed germination and plant development, *Biological Agriculture and Horticulture*, 32(4): 237-247

Gaskin JW, Steiner C, Harris K, Das KC, Bibens B. 2008. Effect of low-temperature pyrolysis conditions on biochar for agriculture use. *Transactions of American Society Agricultural and Biological Engineers*, 51: 2061–2069.

Gichangi EM. 2007. Enhancing phosphorus availability in some phosphate fixing soils of the Transkei region, South Africa, using goat manure. Doctoral dissertation, University of Fort Hare.

Gupta Choudhury S, Srivastava S, Singh R, Chaudhari SK, Sharma DK, Singh SK, Sarkar D. 2014. Tillage and residue management effects on soil aggregation, organic carbon dynamics and yield attribute in rice-wheat cropping system under reclaimed sodic soil. *Soil and Tillage Research*, 136:76–83.

Glaser B, Balashov E, Haumaier L, Guggenberger G, Zech W. 2000. Black carbon in density fractions of anthropogenic soils of the Brazilian Amazon region. *Organic Geochemistry*, 31:669–678.

Glaser B, Lehmann J, Zech W. 2002. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal-a review. *Biology and Fertility of Soils*, 35:219-230.

Gomez JD, Denef K, Stewart CE, Zheng J, Cotrufo MF. 2014. Biochar addition rate influences soil microbial abundance and activity in temperate soils. *European Journal of Soil Science*, 65(1):28-39.

Gomez KA, Gomez, AA. 1984. Statistical Procedures for Agricultural Research. John Wiley and Sons, New York, pp. 68

Hall DJM, Bell RW. 2015. Biochar and compost increase crop yields but the effect is short term on sandplain soils of Western Australia. *Pedosphere*, 25(5): 720–728.

Hamer U, Marschner B, Brodowski S, Amelung W. 2004. Interactive priming of black carbon and glucose mineralisation. *Organic Geochemistry*, 35:823–830

Han P, Zhang W, Wang G, Sun W, Huang Y. 2016. Changes in soil organic carbon in croplands subjected to fertilizer management: a global meta-analysis. *Scientific Reports*, 6:27199.

Hebinck P, Monde N. 2007. Chapter 8: Production of crops in arable fields and home gardens. In Hebinck P, Lent PC. (Eds.), *Livelihoods and landscapes. The people of Guquka and Koloni and their resources*. Brill. Leiden, Boston.

Hebinck P, Van Averbeke W. 2007. Chapter 2: Rural transformation in the Eastern Cape. In Hebinck P, Lent PC. (Eds.), *Livelihoods and landscapes. The people of Guquka and Koloni and their resources*. Brill. Leiden, Boston.

Higashi T, Yunghui M, Komatsuzaki M, Miura S, Hirata T, Araki H, Kaneko N, Ohta H. 2014. Tillage and cover crop species affect soil organic carbon in Andosol, Kanto, Japan. *Soil and Tillage Research*, 138: 64–72.

Hodgson EM, Nowakowski DJ, Shield I, RicheA, Bridgwater AV, Clifton-Brown JC, Donnisona IS. 2011. Variation in Miscanthus chemical composition and implications for conversion by pyrolysis and thermo-chemical bio-refining for fuels and chemicals. *Bioresource Technology,* 102(3): 3411-3418.

Hoffman T, Todd S, Ntshona Z, Turner S. 1999. Land degradation in South Africa. Prepared for Department of Environmental Affairs and Tourism.

Hoffmann I, Gerling D, Kyiogwom UB, Mané-Bielfeldt A. 2001. Farmers' management strategies to maintain soil fertility in a remote area in northwest Nigeria. *Agriculture, Ecosystems and Environment*, 86(3):263–275.

Hossain MK, Strezov VK, Chan Y, Ziolkowski A, Nelson PF. 2011. Influence of pyrolysis temperature on production and nutrient properties of wastewater sludge biochar. *Journal of Environmental Management*, 92: 223-228.

Inal A, Gunes A, Sahin O, Taskin MB, Kaya EC. 2015. Impacts of biochar and processed poultry manure, applied to a calcareous soil, on the growth of bean and maize. *Soil Use and Management*, 31(1): 106–113.

Indegenous poultry breeds South Africa. (2017). http://www.wickedfoodearth.co.za/indigenous-poultry-breeds-in-south-africa/ (Accessed online August 2017).

Jaafar NM, Clode PL, Abbott LK. 2015. Biochar-Soil Interactions in Four Agricultural Soils. *Pedosphere*, 25(5): 729–736.

Jahnke HE. 1982. Livestock Production Systems and Livestock Development in Tropical Africa. Kieler Wissenschaftsverlag Vauk. Kiel.

Jeffery S, Verheijen FG, Kammann C, Abalos D. 2016. Biochar effects on methane emissions from soils: A meta-analysis. *Soil Biology and Biochemistry*, 101:251-258.

Jien SH, Wang CS. 2013. Effects of biochar on soil properties and erosion potential in a highly weathered soil. *Catena,* 110:225–233.

Jin Y, Liang X, He M, Liu Y, Tian G, Shi J. 2015. Manure biochar influence upon soil properties, phosphorus distribution and phosphatase activities: A microcosm incubation study. *Chemosphere*, 142: 128-135

Jindo K, Mizumoto H, Sawada Y, Sonoki T. 2014. Physical and chemical characterization of biochars derived from, *Biogeosciences*, 6613–6621.

Kakembo V, Rowntree KM. 2002. The relationship between land use and soil erosion in communal areas near Peddie Town, Eastern Cape, South Africa. *Land Degradation and Development,* 14: 39 – 49.

Karhu K, Gärdenäs AI, Heikkinen J, Vanhala P, Tuomi M, Liski J. 2012. Impacts of organic amendments on carbon stocks of an agricultural soil - Comparison of model-simulations to measurements. *Geoderma*, 189(190): 606–616.

Kimetu JM, Lehmann J, Ngoze SO, Mugendi DN, Kinyangi JM, Riha S, Verchot L, Recha JW, Pell AN. 2008. Reversibility of soil productivity decline with organic matter of differing quality along a degradation gradient. *Ecosystems*, 11:726–739.

Kirsten JF, Parker AN, Van Zyl J. 1996. Poverty, household food security and agricultural production: Evidence from KwaZulu. *Agrekon*, 35(2):314-319.

Klass DL. 1998. Biomass for Renewable Energy, Fuels, and Chemicals. Elselvier Press, San Diego, CA.

Kloss S, Zehetner F, Wimmer B, Buecker J, Rempt F, Soja G. 2014. Biochar application to temperate soils: Effects on soil fertility and crop growth under greenhouse conditions. *Journal of Plant Nutrition and Soil Science*, 177(1): 3–15.

Knoblauch C, Maarifat A-A, Pfeiffer E-M, Haefele SM. 2011. Degradability of black carbon and its impact on trace gas fluxes and carbon turnover in paddy soils. *Soil Biology and Biochemistry*, 43:1768–1778

Knoepp JD, DeBano LF, Neary DG. 2005. Soil chemistry. In: Neary DG, Ryan KC, DeBano LF (eds) Wildland fire in ecosystem; effect of fire on soils and water. General Technical Report RMRS-GTR 42-4, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT, pp 53–71

Kongthod T, Thanachit S, Anusontpornperm S, Wiriyakitnateekul W. 2015. Effects of biochars and other organic soil amendments on plant nutrient availability in an Ustoxic Quartzipsamment. *Pedosphere*, 25: 790–798.

Lahiff E. 2000. An Apartheid oasis? Agriculture and rural livelihoods in rural Venda. The Library of Peasant Studies. Frank Cass. London.

Laird, DA, 2008. The charcoal vision: a win–win–win scenario for simultaneously producing bioenergy, permanently sequestering carbon, while improving soil and water quality. *Agronomy*, 100: 178-181.

Laird DA, Brown RC, Amonette JE, Lehmann J. 2009. Review of the pyrolysis platform for co-producing bio-oil and biochar. *Biofuels, Bioproducts and Biorefineries*, 3:547–562

Lee Y, Park J, Ryu C, Seop K, Yang W, Park Y, Jung J, and Hyun S. 2013. Comparison of biochar properties from biomass residues produced by slow pyrolysis at 500 ° C. *Bioresource Technology*, 148: 196–201.

Lehmann J, Czimczik C, Laird D, Sohi S. 2009. Stability of biochar in the soil. In: Lehmann J, Joseph S, (eds) Biochar for environmental management: science and technology. Earthscan, London, pp. 183-205.

Lehmann J, da Silva Jr JP, Steiner C, Nehls T, Zech W, Glaser B. 2003. Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. *Plant and Soil*, 249: 343–357.

Lehmann J, Rillig MC, Thies J, Masiello CA, Hockaday WC, Crowley D. 2011. Biochar effects on soil biota – A review. *Soil Biology and Biochemistry*, 43:1812–1836.

Lehmann J, Gaunt J, Rondon M. 2006. Bio-char sequestration in terrestrial ecosystems—A review. *Mitigation and Adaptation Strategies for Global Change*, 11:395–419.

Lehmann J, Joseph S. 2009. Biochar for Environmental Management Science and Technology (eds). *Earthscan*, London. Lehmann,

Lewu FB, Assefa Y. 2009. Farmers' knowledge in the cropping systems of Northern KwaZulu-Natal, South Africa: Current challenges and solution for sustainable future food production. *African Journal of Agricultural Research*, 4(11):1148–1153.

Liang B, Lehmann J, Solomon D, Kinyangi J, Grossman J, O'Neill B, Skjemstad JO, Thies J, Luiza˜o FJ, Petersen J, Neves EG. 2006. Black carbon increases cation exchange capacity in soils. *Soil Science Society of America*, 70:1719-1730.

Liang Y, Cao X, Zhao L, Xu X, Harris W. 2014. Phosphorus release from dairy manure, the manure-derived biochar, and their amended soil: effects of phosphorus nature and soil property. *Journal of Environmental Quality*, 43:1504–1509.

Liu J, Schulz H, Brandl S, Miehtke H, Huwe B, Glaser B. 2012. Short-term effect of biochar and compost on soil fertility and water status of a Dystric Cambisol in NE Germany under field conditions. *Journal of Plant Nutrition and Soil Science,* 175: 698–707

Liu X, Zhang A, Ji C, Joseph S, Bian R, Li L, Pan G, Paz-Ferreiro, J. 2013. Biochar's effect on crop productivity and the dependence on experimental conditions—A meta-analysis of literature data. *Plant and Soil*, *373*(1-2):583-594.

Liu XH, Zhang XC. 2012. Effect of biochar on pH of alkaline soils in the loess plateau: results from incubation experiments. *International Journal of Agriculture and Biology,* 14: 745–750.

Lone AH, Najar GR, Ganie MA, Sofi JA, Ali T. 2015. Biochar for Sustainable Soil Health: A Review of Prospects. *Pedosphere*, 25(5): 639–653.

Lopez-Capel E, Zwart K, Shackley S, Postma R, Stenstrom J, Rasse DP, Budai A, Glaser B. 2016. Biochar properties. In *Biochar in European Soils and Agriculture: Science and Practice* (pp. 41-72). Taylor and Francis Inc., 2016.

Lowder SK, Skoet J, Raney T. 2016. The Number, Size, and Distribution of Farms, Smallholder Farms, and Family Farms Worldwide. *World Development*, 87:16–29.

Maillard E, Angers DA. 2014. Animal manure application and soil organic carbon stocks: a meta-analysis. *Global Change Biology*, 20(2): 666-679.

Major J, Rondon M, Molina D, Riha SJ, Lehmann J. 2010. Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant and Soil*, 333: 117–128.

Mandiringana OT, Mnkeni PNS, Mkile Z, van Averbeke W, Van Ranst E, Verplancke H. 2005. Mineralogy and Fertility Status of Selected Soils of the Eastern Cape Province, South Africa. *Communications in Soil Science and Plant Analysis*, 36 (17-18): 2431–2446.

Manyevere A, Muchaonyerwa P, Laker M, Mnkeni PNS. 2014. Farmers' perspectives with regard to arable crop production and deagrarianisation: an analysis of Nkonkobe Municipality, South Africa. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, 115(1): 41-53.

Martinsen V, Alling V, Nurida N, Mulder J, Hale S, Ritz C, Rutherford D, Heikens A. 2015. pH effects of the addition of three biochars to acidic Indonesian mineral soils. *Journal of Plant nutrition and Soil Science*, 61(5): 821–834

Martinsen V, Mulder J, Shitumbanuma V, Sparrevik M, Børresen T, Cornelissen G. 2014. Farmer-led maize biochar trials: effect on crop yield and soil nutrients under conservation farming. *Journal of Plant Nutrition and Soil Sci*ence, 177(5): 681–695

Masika P, Mafu, JV**.** 2004. Aspects of goat farming in the communal farming systems of the central Eastern Cape, South Africa. *Small Ruminant Research*, 52 (1-2): 161–164.

Materechera SA, Van Averbeke W, Yoganthan J, Harris P. 1998. Current and potential role of manure for soil fertility management in the smallscale farming sector of South Africa. Paper presented at a joint congress of the South African Society of Crop

Production and Soil Science Society of South Africa on "Soils and Crops Towards 2000" held at the Alpine Heath, KZN, 20-22 January 1998.

Mc cain M. 2005 Annexure 2: District Profile Eastern Cape Tambo District Municipality (DC15). Programme of Support to Local Economic Development in the Eastern Cape. Eastern Cape Competitive Advantage Assessment And Training Support Project. European Consultants Organisation (ECO). Accessed online at http://www.thinasinako.co.za/files/documents/290806175904.pdf. on 06/08/2011.

Meyer S, Glaser B, Quicker P. 2011. Technical, economical, and climate-related aspects of biochar production technologies: a literature review. *Environmental Science and Technology*, 45(22): 9473-9483.

Mhlontlo S, Muchaonyerwa P, Mnkeni PNS. 2007. Effects of sheep kraal manure on growth, dry matter yield and leaf nutrient composition of a local Amaranthus accession in the Central Region of the Eastern Cape Province, South Africa. *Water SA*, 33(3): 363-368.

Mkhabela TS, Materechera SA. 2003. Factors influencing the utilization of cattle and chicken manure for soil fertility management by emergent farmers in the moist Midlands of KwaZulu-Natal province, South Africa. *Nutrient Cycling in Agroecosystems*, 65(2):151–162.

Mkhabela TS. 2006. A Review of the Use of Manure in Small-Scale Crop Production Systems in South Africa. *Journal of Plant Nutrition*, *29*(7):1157-1185.

Mkile Z, 2001. The use and agronomic effectiveness of kraal manures in the Transkei region of the Eastern Cape Province, South Africa. M.Sc. Dissertation. University of Fort Hare, Alice, South Africa.

Mnkeni PNS, Chiduza C, Modi AT, Steven J, Monde N, Van Der Stoep I, Dladla R. 2010. Best management practices for smallholder farming on two irrigation schemes and surrounding areas in the Eastern Cape and KwaZulu-Natal Provinces through participatory adaptive research. Water Research Commission TT478/10. Pretoria, South Africa.

Mnkeni PNS, Mkile Z. 2006. Characterization of kraal manure and optimization of its use as a fertilizer in the Eastern Cape Province. Chapter 8. In Van Averbeke W, Harris PJC, Mnkeni PNS, Van Ranst E, Verplancke H (eds). Smallerholder Farming and management of soil fertility in the Eastern Cape, South Africa. UNISA press.

Monde N. 2003. Household food security in rural areas of central Eastern Cape: the case of Guquka in Victoria East and Koloni in Middledrift districts. Ph.D. thesis submitted for examination, University of Fort Hare, Alice.

Muhereza I, Pritchard D, Murray-Prior R. 2014. Utilisation of cattle manure and inorganic fertiliser for food production in central Uganda. *Journal of Agriculture and Environment for International Development*, 108(2): 135-151.

Mukai S. 2017. Data on farmers' determinants of manure and inorganic fertiliser use in the semi-arid Ethiopian Rift Valley. *Data in brief*, 14:804-812.

Mukherjee A, Lal R. 2013. Biochar Impacts on Soil Physical Properties and Greenhouse Gas Emissions. *Agronomy*, 3(2): 313-339.

Mupondi LT. 2010. Improving sanitization and fertiliser value of dairy manure and waste paper mixtures enriched with rock phosphate through combined thermophilic composting and vermicomposting. PhD Dissertation. Alice: University of Fort Hare; 2010.

Murungu, FS. 2010. Evaluation and management of cover crop species and their effect on weed dynamics, soil fertility and maize (Zea may L.) productivity under irrigation in the Eastern Cape Province, South Africa. PhD Dissertation. Alice: University of Fort Hare; 2010.

Murungu FS, Chiduza C, Muchaonyerwa P, Mnkeni PNS. 2011. Decomposition, nitrogen and phosphorus mineralization from winter-grown cover crop residues and suitability for smallholder farming system in South Africa. *Nutrient Cycling in Agroecosystems*, 89: 115-123.

Murwira HK, Swift MJ, Frost PGH. 1993. Manure as a key resource in sustainable agriculture. In: Powell, M.S., Fernandez-Rivera, S., Williams, T.O. & Renard, C. (eds) Livestock and sustainable nutrient cycling in mixed framing systems of Sub-Saharan Africa 2: 131-148. Addis Ababa, Ethiopia: International Livestock Centre for Africa (ILCA).

Mupambwa HA, Ravindran B, Mnkeni PNS. 2016. Potential of effective micro-organisms and Eisenia fetida in enhancing vermi-degradation and nutrient release of fly ash incorporated into cow dung–paper waste mixture. *Waste Management*, 48:165-173.

Musemwa L. Mushunje A, Chimonyo M, Fraser G, Mapiye C, Muchenje V. 2008. Nguni cattle marketing constraints and opportunities in the communal areas of South Africa: Review. *African Journal of Agricultural Research*, 3 (4), 239-245

Muzangwa L, Chiduza C, Muchaonyerwa P. 2012. Biomass production, weed suppression, nitrogen and phosphorus uptake in white oat (Avena sativa L.) and grazing vetch (Vicia dasycarpa L.) cover crop bicultures under an irrigated no-till system. *South African Journal of Plant and Soil*. 29:135-141.

Muzangwa L, Chiduza C, Mnkeni PNS. 2017. Assessment of Conservation Agriculture Practices by Smallholder Farmers in the Eastern Cape Province of South Africa. *Agronomy*, 7(3):46.

Nciizah AD, Wakindiki II. 2012. Aggregate stability and strength of a hardsetting soil amended with cattle manure. *African Journal of Agricultural Research*, *7*(1): 68-73.

Nciizah AD. 2011. Cattle manure and scalping effects on selected physical properties of a hard-setting soil and associated early maize growth. MSc Dissertation. Alice: University of Fort Hare; 2011.

Neary DG, Ryan KC, Debano LF. 2005. 'Wildland fire in ecosystem; effect of fire on soils and water'. Department of Agriculture, Forest Service, Rocky Mountain Research Station

Nelissen V, Rütting T, Huygens D, Staelens J, Ruysschaert G, Boeckx P. 2012. Maize biochars accelerate short-term soil nitrogen dynamics in a loamy sand soil. *Soil Biol Biochem* 55:20–27.

Novak JM, Busscher WJ, Laird DL, Ahmedna M, Watts DW, Niandou MAS. 2009. Impact of biochar amendment on fertility of a Southeastern coastal plain soil. *Soil Science*, 174: 105–112.

Novak JM, Busscher WJ, Watts DW, Laird DA, Ahmedna MA, Niandou MAS. 2010. Short-term CO2 mineralization after additions of biochar and switchgrass to a Typic Kaniudult. *Geoderma*, 154:281–288.

Novak JM, Busscher WJ, Watts DW, Amonette JE, Ippolito JA, Lima IM, Gaskin J, Das KC, Steiner C, Ahmedna M, Rehrah D, Schomberg H. 2012. Biochars impact on soil-moisture storage in an Ultisol and two Aridisols. *Soil Science Journal*, 177: 310–320.

Novak JM, Sigua GC, Spokas KA, Busscher WJ, Cantrell KB, Watts DW, Glaz B, Hunt PG. 2015. Plant Macro- and Micronutrient Dynamics in a Biochar-Amended Wetland Muck. *Water, Air and Soil Pollution*, 226:2228

Odhiambo JJO, Magandini VN. 2008. An assessment of the use of mineral and organic fertilizers by smallholder farmers in Vhembe district, Limpopo province, South Africa. *African Journal of Agricultural Research*, 3(5):357–362.

Odhiambo JJO, Nemadodzi LE. 2007. Soil fertility management practices by smallholder farmers in Vhembe District, Limpopo Province. *South African Journal of Agricultural Extension*, 36(1): 53-61.

Okalebo JR, Gathua KW, Woomer PL. 2002. Laboratory methods of soil analysis: A working manual, second edition. TSBR-CIAT and SACRED Africa, Nairobi, Kenya.

Olsen SR, Cole CV, Wanatabe FS, Dean LA. 1954. Estimation of available phosphorus by extraction with sodium bicarbonate. U.S. Dep. Agric. Circ., p. 939.

Onasanya RO, Aiyelari OP, Onasanya A, Oikeh S, Nwilene FE, Oyelakin OO. 2009. Growth and yield response of maize (Zea mays L.) to different rates of nitrogen and phosphorus fertilizers in southern Nigeria. *World Journal of Agricultural Sciences*, *5*(4):400-407.

Onduru DD, Snijders FN, Muchena FN, Wouters B, De jager A, Gachimbi L, Gachini GN. 2008. Manure and soil fertility management in Sub-Humid and Semi-Arid farming systems of Sub-Saharan Africa: Experiences from Kenya. *International journal of Agricultural Research*, 3(3): 188-187.

Parvage MM, Ulén B, Kirchmann H. 2015. Regional Nutrient leaching from manure-amended topsoils ( Cambisols and Histosols ) in Sweden. *Geoderma*, 5: 209–214.

Parwada C, Van Tol JJ. 2017. Soil properties influencing erodibility of soils in the Ntabelanga area, Eastern Cape Province, South Africa. *Acta Agriculturae Scandinavica, Section B -Soil & Plant Science*. 67(1): 67-76.

Patwardhan PR, Satrio JA, Brown RC, Shanks BH. 2010. Influence of inorganic salts on the primary pyrolysis products of cellulose. *Bioresource Technology*, 101: 4646–4655.

Prayogo C, Jones JE, Baeyens J, Bending GD. 2014. Impact of biochar on mineralisation of C and N from soil and willow litter and its relationship with microbial community biomass and structure. *Biology and Fertility of Soils*, 50:695–702.

Pribyl D. 2010. A critical review of the conventional SOC to SOM conversion factor. *Geoderma*, 156 (3-4): 75-83

Radlein D, Piskorz JK, Majerski P. 1996. Method of producing slow release nitrogenous organic fertilizer from biomass. *U.S. Patent 5,676,727.*

Rajkovich S, Enders A, Hanley K, Hyland C, Zimmerman AR, Lehmann J. 2012. Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil. *Biology and Fertility of Soils*, 48: 271-284

Reay DS, Davidson EA, Smith KA, Smith P, Melillo JM, Dentener F, Crutzen PJ. 2012. Global agriculture and nitrous oxide emissions. *Nature Climate Change*, 2:410–416

Revell KT, Maguire RO, Agblevor FA. 2012. Influence of Poultry Litter Biochar on Soil Properties and Plant Growth. *Soil Science*, 177(6): 402–408.

Rondon MA, Lehmann J, Ramirez J, Hurtado M. 2007. Biological nitrogen fixation by common beans (*Phaseolus vulgaris L.*) increases with biochar additions. *Biology and Fertility of Soils*, 43: 699-708.

Ronsse F, Van Hencke S, Dickinson D, Prins W. 2013. Production and characterization of slow pyrolysis biochar: Influence of feedstock type and pyrolysis conditions. *GCB Bioenergy*, 5: 104–115.

Rumosa-Gwaze F. 2009. Communal Production Systems of Goats Raised by Resource Poor Farmers in the Eastern Cape Province of South Africa. PhD Thesis, University of Fort Hare, Alice, South Africa. www.netd.ac.za.(Accessed on 28 May 2016)

Salako FK, Babalola O, Hauser S, Kang BT. 1999. Soil macroaggregate stability under different fallow management systems and cropping intensities in southwestern Nigeria. *Geoderma*, *91*(1-2):103-123.

Salomon ML. 2011. Keeping cattle in a changing rural landscape: communal rangeland management in Okhombe, KwaZulu-Natal, South Africa (Doctoral dissertation, University of KwaZulu-Natal, Pietermaritzburg).

Sarkhot DV, Berhe AA, Ghezzehei TA. 2012. Impact of biochar enriched with dairy manure effluent on carbon and nitrogen dynamics. *Journal of Environmental Qual*ity, 41:1107–1114.

Schimmelpfenning S, Glaser B. 2012. One step forward toward characterization some important material properties to distinguish biochars. *Journal of Environmental Quality* 41(4): 1001-1013.

Schmidt MWI, Torn MS, Abiven S, Dittmar T, Guggenberger G, Janssens IA, Kleber M, Kogel-Knaber I, Lehmann J, Manning DAC, Nannipieri P, Rasse DP, Weinder S, Trumbore SE. 2011. Persistence of soil organic matter as an ecosystem property. *Nature.* 478(7367): 49-56

Scholtz M, Van Ryssen J, Meissner H, Laker M. 2013. A South African perspective on livestock production in relation to greenhouse gases and water usage. *South African Journal of Animal Science*, 43(3):247.

Schulz H, Glaser B. 2012. Effects of biochar compared to organic and inorganic fertilizers on soil quality and plant growth in a greenhouse experiment. *Journal of Plant Nutrition and Soil Science*, 175:410–422.

Shackleton R, Shackleton C, Shackleton S, Gambiza J. 2013. Deagrarianisation and forest revegetation in a biodiversity hotspot on the Wild Coast, South Africa. .*PLoS One, 8* (10):76939.

Shenbagavalli S, Mahimairaja S. 2012. Characterization and Effect of Biochar on Nitrogen and carbon dynamics in soil. *Internal Journal of Advance Biological Research,* 2(2): 249–255.

Sika, MP. 2012. Effect of biochar on chemistry, nutrient uptake and fertilizer mobility in sandy soil. Doctoral dissertation, Stellenbosch: Stellenbosch University.

Sika MP, Hardie AG. 2014. Effect of pine wood biochar on ammonium nitrate leaching and availability in a South African sandy soil. *European Journal of Soil Science,* 65:113-119.

Sileshi G, Akinnifesi FK, Ajayi OC, Place F. 2008. Meta-analysis of maize yield response to woody and herbaceous legumes in sub-Saharan Africa. *Plant and soil*, 307(1-2):1-19.

Singh BP, Cowie AL, Smernik RJ. 2012. Biochar carbon stability in a clayey soil as a function of feedstock and pyrolysis temperature. *Environmental Science and Technology*, 46(21): 11770-11778.

Singh BP, Hatton BJ, Balwant S, Cowie AL, Kathuria A. 2010. Influence of biochars on nitrous oxide emission and nitrogen leaching from two contrasting soils. *Journal of Environmental Quality*, 39:1224–1235.

Singh R, Srivastava P, Singh P, Upadhyay S, Raghubanshi AS. 2015. Integrating biochar as conservation agriculture tool under climate change mitigation scenario. In *Proceedings of National Conference on Climate Change: Impacts, Adaptation, Mitigation Scenario and Future Challenges in Indian Perspective*.

Sinyolo S. 2013. The impact of smallholder irrigation and water security on household welfare: The case of Tugela Ferry irrigation scheme in KwaZulu-Natal, South Africa. M.Sc thesis. School of Agriculture, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, RSA.

Sohi S, Lopez-Capel E, Krull E, Bol R. 2009. Biochar, climate change and soil: A review to guide future research. *CSIRO Land and Water Science Report*, *5*(09):17-31.

Sohi SP, Krull E, Lopez-Capel E, Bol R. 2010. A review of biochar and its use and functions in soil. *Advances in Agronomy*; 105: 47-82

Soil Sampling and Methods of Analysis. 2006. Second Edition. Edited by Carter M.R. and Gregorich E.G. Canadian Soc iety of Soil Science. © 2008 by Taylor & Francis Group, LLC.

Soil classification working group, 1991. Soil classification, a taxonomic system for South Africa. Memoirs concerning the natural agricultural resources of South Africa.

Soil Survey Staff. 1999. Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys, Second Edition. United States Department of Agriculture, Agriculture Handbook No. 436, Washington D.C.

Solaiman ZM, Anawar HM. 2015. Application of Biochars for Soil Constraints: Challenges and Solutions features of this biochar special issue. *Pedosphere*, 25(5): 631–638.

Song Y, Zhang X, Ma B, Chang SX, Gong J. 2013. Biochar addition affected the dynamics of ammonia oxidizers and nitrification in microcosms of a coastal alkaline soil. *Biology and Fertility of Soils*, 50:321–332

Spokas KA, Cantrell KB, Novak JM, Archer DW, Ippolito JA, Collins HP, Boateng AA, Lima IM, Lamb MC, McAloon AJ, Lentz RD, Nichols KA. 2012. Biochar: A synthesis of its agronomic impact beyond carbon sequestration. *Journal of Environmental Quality,* 12: 78-89.

Spokas KA, Novak JM, Stewart CE, Cantrell KB, Uchimiya M, DuSaire MG, Ro KS. 2011. Qualitative analysis of volatile organic compounds on biochar. *Chemosphere*, 85: 869–882.

SPSS Inc. (2008). *SPSS Statistics 17.0*. SPSS Inc.,Chicago IL.

STATS SA (2001). Census, 2001. Pretoria. URL http://www.statssa.gov.za/census01/html/ last accessed 15.09.2016.

Stella Mary G, Sugumaran P, Niveditha S, Ramalakshmi B, Ravichandran P, Seshadri S. 2016. Production, characterization and evaluation of biochar from pod (Pisum sativum), leaf (Brassica oleracea) and peel (Citrus sinensis) wastes. *International Journal of Recycling of Organic Waste in Agriculture*, 5(1):43–53.

Tagar A, Adamowski J. 2015. The stability of soil aggregates in tilled fallow areas in Hyderabad district, Pakistan. *Journal of Water and Land Development*, 27 (1):51-60.

Theriault V, Smale M, Haider H. 2017. How Does Gender Affect Sustainable Intensification of Cereal Production in the West African Sahel? Evidence from Burkina Faso. *World Development*, 92: 177–191.

Thornton PK, Herrero M. 2001. Integrated crop-livestock simulation models for scenario analysis and impact assessment. *Agricultural Systems*, 70 (2-3): 581-602.

Thornton PK, Herrero M. 2010. Potential for reduced methane and carbon dioxide emissions from livestock and pasture management in the tropics. *Proceedings of the National Academy of Sciences*, 107:19667–19672.

Touray N, Tsai W, Chen, H, and Liu S. 2014. Thermochemical and pore properties of goat-manure-derived biochars prepared from different pyrolysis temperatures. Journal of *Analytical and Applied Pyrolysis*, 109: 116–122.

Torres-Rojas D, Lehmann J, Hobbs P, Joseph S, Neufeldt H. 2011. Biomass availability, energy consumption and biochar production in rural households of Western Kenya. *Biomass and Bioenergy*, 35: 3537–3546.

Tsai WT, Liu SC, Chen HR, Chang YM, Tsai YL. 2012. Textural and chemical properties of swine-manure-derived biochar pertinent to its potential use as a soil amendment. *Chemosphere*, 89:198-203.

Ukonze, JA, Akor VO, Ndubuaku, UM. (2016). Comparative analysis of three different spacing on the performance and yield of late maize cultivation in Etche local government area of Rivers State, Nigeria. *African Journal of Agricultural Research*, 11(13):1187-1197

Utomo WH, Guritno W, Soehono BL. 2012. The Effect of Biochar on the Growth and N Fertilizer Requirement of Maize (Zea mays L.) in Green House Experiment. *Journal of Agricultural Science*, 4(5): 255–262.

Uzoma KC, Inoue M, Andry H, Fujimaki H, Zahoor A, Nishihara E. 2011. Effect of cow manure biochar on maize productivity under sandy soil condition. *Soil Use and Management*, 27 (2): 205–212.

Vassilev N, Martos E, Mendes G, Martos V, Vassileva M. 2013. Biochar of animal origin: a sustainable solution to the global problem of high-grade rock phosphate scarcity? *Journal of the Science of Food and Agriculture*, 93: 1799–1804

Valbuena D, Erenstein O, Homann-Kee Tui S, Abdoulaye T, Claessens L, Duncan AJ, Gérard B, Rufino MC. 2012. Conservation Agriculture in mixed crop-livestock systems: Scoping crop residue trade-offs in Sub-Saharan Africa and South Asia. *Field Crops Research*, 132:175–184.

Van Averbeke W, Harris PJC, Mnkeni PNS, Van Ranst E, Verplancke H. 2006. Smallholder Farming and Management of Soil Fertility in the Eastern Cape, South Africa. (11-chapter-book), UNISA Press .

Van Averbeke W, Marais JN. 1991. An evaluation of Ciskeian ecotopes for rainfed cropping: final report. ARDRI, University of Fort Hare, Alice, S.A.

Van Averbeke W, Mnkeni PNS, Harris PJC, Mkile Z. 2008. Fertility status of cropped soils in smallholder farming systems of the Transkei region, Eastern Cape Province, South Africa, 1–15. In *Proceedings of the 15th International Symposium of the International Scientific Centre for Fertilizers, 27-30 September 2004, Pretoria, South Africa: Fertilizer and Fertilization for Sustainability in Agriculture: The First World meets the Third World-Challenges for the Future* (pp. 513-526).

Van Averbeke W, Bennett J. 2007. Chapter 3: Agro-ecology, land use and smallholder farming in the central Eastern Cape. In Hebinck P, Lent PC. (Eds.), *Livelihoods and landscapes. The people of Guquka and Koloni and their resources*. Brill. Leiden, Boston.

Van Wambeke A. 1992. Soils of the Tropics. McGraw-Hill, New York.

Van Zwieten L, Singh BP, Joseph S, Kimber S, Cowie A, Chan Y. 2009. Biochar and emissions of non-$CO_2$ greenhouse gases from soil. In: Biochar for Environmental

Management: Science and Technology, (eds Lehman J and Joseph S). Earthscan, Oxford.

Van Zwieten L, Kimber S, Morris S, Chan K, Downie A, Rust J, Joseph S, Cowie A. 2010. Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. *Plant and Soil*, 327: 235–246.

Verheijen FG, Graber ER, Ameloot N, Bastos C, Sohi S, Knicker H. 2014. Biochars in soils: New insights and emerging research needs. *European Journal of Soil Science*. 65(1):22–27.

Waithaka MM, Thornton KP, Shepherd KD, Ndiwa NN. 2007. Factors affecting the use of fertilizers and manure by smallholders: the case of Vihiga , Western Kenya. *Nutrient Cycling in Agroecosystems*, 78:211–224.

Wang Y, Lin Y, Chiu PC, Imhoff PT, Guo M. 2015. Phosphorus release behaviors of poultry litter biochar as a soil amendment. *Science of the Total Environment*, 512–513, 454–463.

Wardle DA, Nilsson M-C, Zackrisson O. 2008. Fire-derived charcoal causes loss of forest humus. *Science,* 320(5876):629-629

Wu H, Yip K, Kong Z, Li CZ, Liu D, Yu Y, Gao X. 2011. Removal and recycling of inherent inorganic nutrient species in Mallee biomass and derived biochars by water leaching. *Industrial and Engineering Chemistry Research*, 50: 12143–12151.

Wuta M, Nyamugafata P. 2012. Management of cattle and goat manure in Wedza smallholder farming area, Zimbabwe. *African Journal of Agricultural Research,* 7(26):3853–3859.

Yoganathan S, Sotana MM, Van Averbeke W, Mandiringana OT, Materechera S, Harris PJC, Mnkeni PNS. 1998. Kraal manure as a fertilizer for small-scale crop production in Central Eastern Cape, South Africa. Proceedings of AFSR-E 15th International Symposium, Vol. 1, University of Pretoria: 361-368.

Yuan JH, Xu RK. 2011. The amelioration effects of low temperature biochar generated from nine crop residues on an acidic Ultisol. *Soil Use Management*. 27:110–115.

Zhao L, Cao X, Mašek O, Zimmerman A. 2013. Heterogeneity of biochar properties as a function of feedstock sources and production temperatures. *Journal of Hazardous Materials,* 256-257, 1–9.

Zhao R, Coles N, Wu J. 2015. Catena Carbon mineralization following additions of fresh and aged biochar to an infertile soil. *Catena*, 125: 183–189.

Zheng H, Wang ZY, Deng X, Zhao J, Luo Y, Novak J, Herbert S, Xing BS. 2013. Characteristics and nutrient values of biochars produced from giant reed at different temperatures. *Bioresource. Technology*, 130: 463-471.

Zhuang M, Li W. 2017. Greenhouse gas emission of pastoralism is lower than combined extensive / intensive livestock husbandry: A case study on the. *Journal of Cleaner Production*, 147: 514–522.

Zhu QH, Peng XH, Huang TQ, Xie ZB, Holden NM. 2014. Effect of biochar addition on maize growth and nitrogen use efficiency in acidic red soils. *Pedosphere*, 24: 699–708.

Zornoza R, Acosta JA, Muñoz MA, Faz A. 2016. Stability, nutrient availability and hydrophobicity of biochars derived from manure, crop residues, and municipal solid waste for their use as soil amendments. *Chemosphere*, 144: 122–130.

# APPENDICES

## Appendix 1: Questionnaire used in the formal survey

UNIVERSITY OF FORT HARE

FACULTY OF SCIENCE AND AGRICULTURE

Department of Agronomy

**QUESTIONNAIRE FOR PROJECT-** LIVESTOCK MANURE AVAILABILITY AND UTILIZATION NKONKOBE MUNICIPALITY, SOUTH AFRICA

All information provided will be treated as STRICTLY CONFIDENTIAL

**Questionnaire Identification**

Questionnaire number
Name of interviewer
Village
GPS coordinates

**1. Household characteristics**

1.1. Gender of the household head a) Male ☐ b) Female ☐

1.2. Educational level of household head

a) Can't read/write ☐ b) Primary ☐ c) Secondary ☐ d) Tertiary ☐

1.3. How many people stay permanently in the household for each age bracket?

Children < 6 years ___
Children 6≤17 years ___
Adults 18-45 years ___
Adults 45-60 years ___
Elderly 60+ years ___

1.4. What is your main source of income?

**Circle only one**
Selling cattle------------------------1
Selling goats------------------------2
Selling sheep ----------------------3
Selling chicken----------------------4
Cow milk----------------------------5
Salary--------------------------------6
Pension------------------------------7
Child maintenance-----------------8
Grants--------------------------------9
Crop production------------------10

1.5. What are you other sources of income?

**Circle all those that applies to you**

Selling cattle-------------------------1
Selling goats-------------------------2
Selling sheep -----------------------3
Selling chicken----------------------4
Cow milk----------------------------5
Salary--------------------------------6
Pension------------------------------7
Child maintenance-----------------8
Grants--------------------------------9
Crop production-------------------10

**2. Household Resource base**

**A. Livestock**

2.1. Do you have any livestock? a) Yes ☐ b) No ☐

2.2. If yes, what is your main livestock species you keeping?

**Circle only one**

Cattle---------------------------------------1
Goats---------------------------------------2
Sheep ------------------------------------3
Chicken-----------------------------------4
Other (specify)----------------------------5
a. ---------------------------------------6
b. ---------------------------------------7
c. ---------------------------------------8

2.3. Provide how many of the following livestock species you keeping?

| **Livestock type** | **Size of flock or herd** |
|---|---|
| Sheep | |
| Goat | |
| Cattle | |
| Chicken | |
| Other (specify) | |
| 1. ------------- | |
| 2. ------------- | |
| 3. ------------- | |

2.4. What is the main reason for keeping each type of livestock? (**TICK** the appropriate box)

| | Cattle | Goats | Sheep | Chicken |
|---|---|---|---|---|
| Milk for sale | | | | |
| Milk for home consumption | | | | |
| Sale live animals to raise income | | | | |
| Home consumption (Home | | | | |

slaughter)
Hobby or cultural reasons
Eggs for home consumption
Eggs for sale
Other (Specify)
1. ------------
2. ------------
3. ------------

**B. Land**

2.1. Do you have cropland allocation? a) Yes ☐ b) No ☐

2.2. What is the land allocation for?
Crop fields (outfields) -----------------------------------------------------------------------
Home Garden --------------------------------------------------------------------------------

**C. Crop Production**

2.0. Are you currently growing crop? a) Yes ☐ b) No ☐
2.1. If yes, what main crops are gown?
------------------------------------------------------------------------
----------------------------------------------------------------------------------

**3. Manure management practices**

3.1. If you keep livestock, do you kraal livestock during the night
a) Yes ☐ b) No ☐
3.2. If you enclose in a kraal, do you use manure in cropping?
a) Yes ☐ b) No ☐

3.3. Specify the quantities allocated for each of the use(s) named above
----------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------------------------------
---------------------

3.4. Give/ describe how application of manure you use when applying to crop fields/ or home garden?

--------------------------------------------------------------------------------------------------
3.5. Tick preferred manure type/s for utilization

a) Goat ☐ b) Sheep ☐ c) Chicken ☐ c) Cattle ☐
d) Other (specify) -----------------------------------------------------------------------------

3.6. Provide the reasons for your choices (*easy to handle, less odor, higher crop yields e.t.c*)
--------------------------------------------------------------------------------------------------

3.7. What are the problems you encounter when using manure? (*Inadequate manure/labor*, *transport to fields*, *weeds e.t.c*)

-----------------------------------------------------------------------------------------------------------