

**EFFECT OF BIOCHAR DERIVED FROM DIFFERENT FEEDSTOCKS  
ON NITROGEN RETENTION, AVAILABILITY, AND UPTAKE BY A  
MAIZE CROP**

**By**

**KHETHANI THAKHANI THRYPHOUS**

**Student Number: 11634776**

**Dissertation submitted in fulfilment of the degree of  
Master of Science in Agriculture (Soil Science)**

**in the**

**DEPARTMENT OF PLANT AND SOIL SCIENCES**

**FACULTY OF SCIENCE, ENGINEERING AND AGRICULTURE**

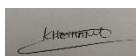
**UNIVERSITY OF VENDA**

## DECLARATION

---

I, Khethani Thakhani Thryphous, student number: 11634776, hereby declare that this Dissertation for Master of Science in Agriculture (Soil Science) submitted to the Department of Plant and Soil Sciences, Faculty of Science, Engineering and Agriculture, University of Venda has not been previously submitted for any degree at this or any other university or institution. Any reference to work done by any other person or institute or any material obtained from other sources have been duly cited and referenced.

Student: Ms Khethani T.T



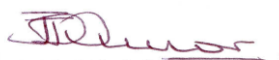
Signature

17 May 2024

Date

As the supervisor/co-supervisor of the candidate, I agree to the submission of this dissertation.

Supervisor: Prof J.J.O Odhiambo



Signature

17 May 2024

Date

Co-supervisor: Dr S.G Lusiba



Signature

17 May 2024

Date

## ACKNOWLEDGEMENTS

---

First, I am grateful to the almighty God for helping me complete my project work. Many people have helped make this dissertation a reality.

Without them, it would have been impossible to start this task, let alone complete it. It is my pleasure to thank them here.

- I want to express my deep gratitude to Professor J.J.O. Odhiambo, my research supervisor, for his patient guidance, enthusiastic encouragement, and useful critiques of this research work.
- I want to express my profound gratitude to Dr Lusiba S. G., my research co-supervisor, for her invaluable support, encouragement, supervision, and useful suggestions throughout this project's work.
- I would also like to thank Muswubi E.P. and Lekgau P. for their assistance with the production of biochar.
- My special thanks to the National Research Foundation (NRF) for awarding me the Deutscher Akademischer Austauschdienst (DAAD) Masters Scholarship, Grant number (UID 117783).
- I'd also like to thank Rambau M for his assistance with data analysis throughout the course of this project.
- I would also like to thank my brother, Mukhodesi Muthige for his support and his love.
- Finally, my heartfelt gratitude goes out to my mother, Ms. Queen Khethani, and my twin sister, Bronie Khethani, as well as my other siblings, for believing in my abilities.
- Above all, let me thank my late grandmother, Ms. Agnes Khethani, for inspiring and encouraging me to be a hard worker.

## DEDICATION

---

I dedicate this dissertation to my late grandmother Ms. A.A. Khethani, my late uncle Mr. P.T. Khethani, my late nephew D.N. Madonsela, my current nephew Mashaba N.G, my mother Ms. Q.T. Khethani, my father Mr. M.L. Phuravhathu, my grannies Mrs. C.N Mahanya, Mr. and Mrs. Tshifure, my twin sister Ms. M.B. Khethani, my siblings, Mashaba A.M, Khethani A.R, Khethani B.O and my family.

*Thank you for your endless love, support, and encouragement.*

## ABSTRACT

---

Nitrogen (N) is an essential nutrient for most crops and can be provided directly by fertilisation or indirectly through atmospheric deposition, fixation, all of which can then be converted to nitrate through mineralization and nitrification. Incomplete N utilisation by crops leaves residual soil nitrate, which is water soluble and susceptible to leaching into groundwater, particularly in regions dominated by light-textured sandy soils with low WHC. Application of biochar (BC) can potentially have a significant impact on nitrogen retention and availability. BC is a charcoal-like substance that's made by burning organic material from agricultural and forestry wastes (also called biomass) in a controlled process called pyrolysis. Biochar can increase organic matter content, act as a liming agent, add basic cations and micronutrients, improve water holding capacity, and release nutrients gradually to the growing plant. This study evaluated the effect of BC derived from different feedstock on nitrogen retention and availability.

Two experiments, laboratory (column leachate) and nursery experiments were conducted at the University of Venda Soil Science Laboratory and the School of Agriculture Experimental Farm, respectively. The treatments in both experiments 1 and 2 consisted of a factorial combination of BC from three different feedstocks (acacia, hay, and poultry litter) and three BC application rates (0%, 1%, and 2%). In experiment 1, the levels of  $\text{NH}_4^+$  and  $\text{NO}_3^-$  leached from and retained in the soil were determined in the laboratory experiment before and after 70-day leaching period. The columns were first filled with three kilograms of the soil-BC mixture based on the previously mentioned treatments, giving rise to an initial bulk density of roughly  $1.5 \text{ g/cm}^3$ . A single fertiliser application with 100 mg of solutioned ammonium nitrate ( $\text{NH}_4\text{NO}_3$ ) was applied to each column. The fertilizer was applied to each column's surface in uniform drips after being diluted in 5 millilitres of distilled water. In the laboratory, the columns were maintained at room temperature, or roughly  $23^\circ\text{C}$ . Every two weeks, 200 ml of distilled water was added to each column through a funnel that was placed above the center of each column. To aid in the dispersal of the water drips, filter papers were placed on the soil surface of the columns. Columns were allowed to drain freely during the leaching process, and all leachate samples were collected in foil-wrapped Erlenmeyer flasks to minimize evaporative loss. For 10 weeks (seventy days), columns were leached every two weeks. Every two weeks, the leachates were collected and chilled before analysis to minimize the growth of algae. Leachates were collected every two weeks, and the pH and electrical conductivity (EC) were measured. The leachate samples were then filtered through Whatman No. 42 filter paper to measure the amounts of nitrite ( $\text{NO}_3^-$ ) and ammonium ( $\text{NH}_4^+$ ). In experiment 2, which was conducted in a nursery, 5 kg of soil was placed in pots measuring 25 cm in height and 25 cm in diameter. Maize (*Zea mays* L.) was used as a test crop and harvested 56 days after planting.

The measurements made in this experiment were dry matter (kg) and nitrogen uptake (kg/ha). A uniform application of nitrogen fertilizer (LAN) at a rate of 100 kg N/ha was given to each pot. The soils were treated with BC as per the stated application rates and ammonium nitrate fertilizer one week prior to planting. The treatments were arranged in a completely random design (CRD) The pots were wetted to 60% field capacity (FC) and allowed to dry out for 24 hours prior to planting. Three maize seeds were planted in each pot. After watering, the pots were filled to 60% of their field capacity (FC). After being allowed to develop for a maximum of eight weeks (56 days), maize crops were collected, dried, weighed, ground, and the N content determined.

In experiment 1, the current study's findings show that using BC can significantly reduce the leaching of highly mobile nutrients like  $\text{NH}_4^+$  and  $\text{NO}_3^-$ . The total amount of leachates collected increased by 46% and 42% at the 1% and 2% biochar application rates, respectively. The amount of ammonium and nitrate retained increased by 1.62% and 16.2% at a 2% rate of application, respectively. In comparison to the control, where no BC was added, BC significantly reduced ammonium leaching at 1% on days 56-70 and 2% (w/w) in BC-amended soils. Biochar increased EC in all BT and retained  $\text{NH}_4^+$  and  $\text{NO}_3^-$ . In experiment 2, this study has shown that feedstock type significantly affects biomass accumulation and N uptake. Biomass yield and N uptake increased in the order poultry litter > acacia > hay. Increasing biochar rates from 0 to 2% increased biomass accumulation and N uptake. In summary, biochar type and rate of application have a potential effect on N leaching and retention in the soil, as well as the biomass and N uptake and therefore these factors should be considered when biochar is used as a soil amendment, especially for N management in agricultural systems.

**Key Words:** Biochar, Nitrogen (N), Nitrogen retention, Nitrogen availability

## TABLE OF CONTENT

---

DECLARATION	xiv
ACKNOWLEDGEMENTS	xv
DEDICATION	xvi
ABSTRACT	xvii
TABLE OF CONTENT	xix
LIST OF TABLES	xxii
LIST OF FIGURES	xxiii
LIST OF ABBREVIATIONS	xxiv
PREFACE	xxv
CHAPTER 1: INTRODUCTION	1
1.1 Background information	1
1.2 Problem statement	2
1.3 Motivation	3
1.4 Objectives	3
1.4.1 Overall objective	3
1.4.2 Specific objective	3
1.5 Hypothesis	3
CHAPTER 2: LITERATURE REVIEW	4
2.1 Biochar definitions	4
2.2 Potential uses of biochar	5
2.3 Biochar production	6
2.4 Biochar physical properties	5
2.5 Biochar biological properties	6
2.6 Biochar effect on soil nitrogen	7
2.7 Biochar effect on soil nitrogen processes	8
2.7.1 Mineralisation	8
2.7.2 Immobilisation	9

2.7.3 Nitrification	10
2.7.4 Leaching	10
CHAPTER 3: MATERIAL AND METHODS	12
3.1 Soil sampling for use in the study	12
3.2 The experiments	12
3.3 Soil analysis	12
3.4 Biochar preparation and characterisation	12
3.5 Experiment 1 (Laboratory experiment) set up and design	13
3.5.1 Leachate collection and analysis	13
3.5.2 Determination of exchangeable inorganic N at the end of the leaching period	14
3.6 Statistical Analysis	14
3.7 Experiment 2 (nursery experiment) set up and design	13
3.7.1 Determination of plant parameters	14
3.7.1.1 Biomass accumulation	14
3.7.1.2 Plant tissue analysis	15
3.7.1.2.1 N concentration	15
3.7.1.2.2 N uptake	15
3.8 Statistical analysis	15
CHAPTER 4: RESULTS AND DISCUSSION	16
4.1 Physico-chemical properties of the Soil	16
4.2 Chemical composition of acacia, poultry litter, and hay biochar	17
4.3 Experiment 1	17
4.3.1 Effect of biochar type on concentration of $\text{NH}_4^+$ leached during the 70-day period	20
4.3.2 Effect of biochar application rate on concentration of $\text{NH}_4^+$ leached during the 70-day leaching period	16
4.3.3 Interactive effect of biochar type and rate of application on concentration of ammonium leachate during the 70-day leaching period	17
4.3.4 Effect of biochar type on concentration of $\text{NO}_3^-$ leached during the 70-day leaching period	20

4.3.5 The effect of biochar rate of application on concentration of $\text{NO}_3^-$ leached during the 70-day leaching period	216
4.3.6 Interactive effect of biochar type and rate of application on EC of leachate during the 70-day leaching period	17
4.3.7 Nitrate ( $\text{NO}_3^-$ ) and ammonium ( $\text{NH}_4^+$ ) retention at the end of the 70-day leaching period	20
4.3.8 Effect of biochar type and rate of application on nitrate and ammonium retention at the end of the 70-day leaching period.	28
4.2 Experiment 2	30
4.2.1 Biomass accumulation and N uptake	30
4.2.2 Effect of biochar type and rate of application on biomass and N uptake of maize	
	<b>Error! Bookmark not defined.</b>
<b>CHAPTER 5: CONCLUSION AND RECOMMENDATIONS</b>	
5.1 Conclusion	33
5.2 Recommendations	33
<b>REFERENCES</b>	<b>34</b>
<b>APPENDIX A: EFFECTS OF BIOCHAR TYPE AND RATE OF APPLICATION ON <math>\text{NH}_4^+</math> AND <math>\text{NO}_3^-</math>, pH AND EC</b>	<b>42</b>
<b>APPENDIX B: TURNITIN REPORT</b>	<b>44</b>

## LIST OF TABLES

---

Table 1: Physiochemical properties of the soil .....	16
Table 2: Chemical composition of acacia, poultry litter and hay used in the study.....	17
Table 3: Total amount of leachate (ml) collected after leaching interval.....	19
Table 4: Effect of biochar type and rate of application on nitrate and ammonium retention at the end of the 70-day leaching period .....	29
Table 5: Effect of biochar type and rate of application on biomass accumulation and N uptake .....	32

## LIST OF FIGURES

---

Figure 1: Effect of biochar type on concentration of ammonium leached after (70) days .....	21
Figure 2: Effect of rate of application on concentration of ammonium leached during the 70-day leaching period.....	22
Figure 3 The interactive effects of biochar type and rate of application on concentration of ammonium leachate after (70) days during the 70-day leaching period.:.....	24
Figure 4: Effect of biochar type on concentration of nitrate $\text{NO}_3^-$ leached after (70) days during the 70-day leaching period.....	25
Figure 5 Effect of rate of application on $\text{NO}_3^-$ concentration during the 70-day leaching period. of nitrate leached after (70) days:.....	26
Figure 6: Interactive Effects of biochar type and rate of application on leachate EC values after (70) days during the 70-day leaching period. ....	28
Figure 7: Effect of biochar type and rate of application on concentration of nitrate after (70) days .....	42
Figure 8: Effect of biochar type and rate of application on leachate pH values after (70) days .....	43

## LIST OF ABBREVIATIONS

---

ANOVA	ANALYSIS OF VARIANCE
BC	BIOCHAR
BT	BIOCHAR TYPE
CRD	COMPLETELY RANDOM DESIGN
DAP	DAYS AFTER PLANTING
FC	FIELD-CAPABLE
FT-IR	FOURIER TRANSFORM-INFRARED
LSD	LEAST SIGNIFICANT DIFFERENCE
N <sub>2</sub>	NITROGEN gas
NH <sub>3</sub>	AMMONIA
NH <sub>4</sub> <sup>+</sup>	AMMONIUM
NO <sub>3</sub> <sup>-</sup>	NITRATE
RA	RATE OF APPLICATION
SEM	SCANNING ELECTRON MICROSCOPY
WHC	WATER HOLDING CAPACITY
N	NITROGEN
NO	NITROGEN MONOXIDE
NO <sub>2</sub>	NITROGEN OXIDE

## PREFACE

---

This dissertation contains five chapters. Chapter one delivers the background, objectives, and justification of the study. Chapter two provides a general review of the up-to-date literature for the research study. Chapter three include information on the materials and methods used in this study. The fourth chapter consist of the results and discussion, while the fifth chapter consists of the conclusions and recommendations for future research.

## CHAPTER 1: INTRODUCTION

---

### 1.1. Background information

Nitrogen (N) is a crucial nutrient for the growth of most crops and can be introduced into the soil in various ways, such as through fertilisation, atmospheric deposition, irrigation water, or fixation. Once in the soil, nitrogen can be converted into nitrate through processes called mineralisation and nitrification (Randall and Mulla, 2001). Poor utilisation of applied nitrogen in the soil may result in the loss of water-soluble soil nitrate by leaching into groundwater, particularly in regions with mostly sandy soils that have low water-holding capacity. This results in substantial losses of applied nitrogen, which in turn has severe environmental consequences, including eutrophication and other water quality problems (De Jonge et al, 2002). Hence, it is essential to devise approaches or tactics that may optimise the retention of nitrogen in the soil to guarantee its optimal availability and uptake by plants.

Nitrate leaching reduces nitrogen utilisation efficiency in a variety of field crops produced under different environmental conditions (Camargo and Alonso, 2006). The majority of nitrogen fertiliser added to soils comes in the form of ammonium or ammonium-producing compounds such as urea, which is quickly oxidised to nitrate by soil nitrifying bacteria. Reducing nitrogen losses due to leaching may be accomplished by slowing the biological oxidation of ammonium (Choudhury and Kennedy, 2005). Gaseous emissions ( $N_2$ ,  $NO_2$ ,  $NO$ ,  $NH_3$ ), ammonium ( $NH_4^+$ ) leaching, and nitrate ( $NO_3^-$ ) leaching all contribute to nitrogen losses in agricultural soils (Robertson et al, 2007).

Many short-term studies have demonstrated that biochar decreases N leaching and availability (Steiner et al, 2008); however, more research needs to be done on the subsequent use of nitrogen in the soil-biochar environment following leaching. It is possible to close this information gap with stable N isotopes. However, there is a lot of disagreement in science on the chemical makeup of soil N since different methods fail to account for a significant portion of it. According to Smernik and Baldock (2005), a large portion of the N is referred to as "heterocyclic N," which is utilized to explain the unidentified N proportions.

Biochar, also known as biomass-derived charcoal, is a strongly aromatic substance that is produced as a byproduct of pyrolysis and biomass carbonisation. It is created in an environment with little or no oxygen present. Biochar may be produced from a diverse range of biomass sources, such as woody materials, agricultural residues including corncobs and cereal straw, animal manures, and other forms of waste. BC has enhanced stability against decomposition and possesses a greater capability to adsorb ions in soil compared to other

forms of soil organic matter. This is attributed to its increased surface area, negative surface charges, and density charges (Liang et al, 2006). Biochar has been shown to influence the nitrogen dynamics in soil by altering the rates of transformation processes (Clough et al, 2013; Clough and Condon, 2010).

When biochar is added to these highly leached, infertile soils, the availability of some basic cations increases almost instantly (Glaser et al, 2002; Liang et al, 2006). Additionally, crop yields are significantly improved, especially in situations where there are limited nutrient resources (Lehmann and Rondon 2006). By increasing the stability of organic matter and therefore reducing its release of nutrients, these additions gradually increase soil nutrient availability (Glaser et al., 2001; Lehmann and Rondon 2006).

During the plant development phase, BC may minimise N runoff and leaching losses and make the nutrient more accessible to plants (Ding et al, 2010; Kookana, 2010). Biochar may also cause microbial nitrogen immobilisation in soil (Zavalloni et al, 2011). Aside from that, applying BC to soils offers a slew of additional potential agricultural advantages. These include liming acid soils, adding basic cations and micronutrients, increasing water retention capacity, and gradually releasing nutrients to developing plants (Laird et al, 2010; Sohi et al, 2010; Van Zwieten et al, 2010 Glaser et al, 2002).

## **1.2. Problem statement**

Nitrogen losses occur in agricultural systems in various ways. Nitrogen from commercial fertilisers is applied directly to the soil system in a variety of forms, the most common of which are ammonium, nitrate, and urea. Precipitation also adds nitrogen, mostly as nitrate and ammonium. The nitrate ion has a negative charge and is weakly linked to negatively charged soil particles. Because nitrate is retained loosely in the soil, it may be leached through the soil profile by rainfall or irrigation. Soils may lose nitrogen by leaching, but soils with poor drainage can lose nitrogen through denitrification. Overwatering removes nutrients from the soil, resulting in reduced soil fertility and crop output. Nitrate is constantly present in soil solutions and due to its high solubility, moves with the soil water. Appropriate measures are therefore necessary to minimise nitrogen losses and increase nitrogen availability for crop uptake and hence yield, while minimizing environmental pollution through N leaching into groundwater sources.

Biochar (charred biomass for soil application) amendment of soils is a potential long-term approach or strategy that can be adopted for mitigating the negative effects of nitrogen fertiliser leaching on surface and groundwater quality. The addition of BC to sandy soils looks to be particularly advantageous since charcoal has a high water-holding capacity. With the increase in electrostatic adsorption sites generated by BC additions, soil water retention and,

surely, nutrient retention are feasible. Biochar has been demonstrated to reduce ammonium and nitrate leaching from both organic and inorganic N sources in coarse-textured soils (Ding et al, 2010). The decrease in N leaching achieved varies substantially depending on the properties of the BC, the volume applied, and the soil type (Wang et al, 2015).

### **1.3. Motivation**

Nitrogen is a crucial component for the growth of plants and is often one of the most constraining elements in agricultural settings. Biochar may impact the way nitrogen is processed in soil systems by affecting the rates of nitrification and the adsorption of ammonia. Additionally, it can increase the storage of nutrients by boosting the soil's ability to exchange cations, as well as other physical, chemical, and biological aspects of the soil. The effect on these processes may potentially reduce N losses, such as nitrate leaching. Biochars, particularly those with a significant surface area (Yao et al, 2012), have shown considerable promise in mitigating the loss of inorganic nitrogen via leaching studies. Therefore, by utilising biochar derived from different locally accessible sources to evaluate the retention and accessibility of nitrogen, a suitable recommendation can be made regarding the use of appropriate biochar as a soil amendment for nitrogen management. This will help minimise losses and maximise crop uptake and yield, ultimately resulting in improved agricultural productivity, food security, and increased income for farmers.

### **1.4 Objectives**

#### **1.4.1. Overall objective**

To determine the impact of biochar generated from various feedstocks on the retention, availability, and absorption of nitrogen by a maize crop.

#### **1.4.2. Specific objective**

The following are the specific objectives identified in this research study, to determine:

- Nitrate and ammonium ( $\text{NO}_3^-$  and  $\text{NH}_4^+$ ) leach from soil;
- Soil nitrate and ammonium ( $\text{NO}_3^-$  and  $\text{NH}_4^+$ ) retention;
- N uptake by the maize plant.

### **1.5. Hypothesis**

Applying biochar as a soil amendment will enhance nitrogen retention, reduce nitrogen leaching from the soil, and promote nitrogen absorption by maize crops.

## CHAPTER 2: LITERATURE REVIEW

---

### 2.1. Biochar definition

Biochar, a residue produced via the process of pyrolysis, is formed from biomass containing black carbon and is used to improve soil quality (Lehmann and Joseph 2011). Biochar is a carbonaceous material produced by subjecting biomass to high temperatures in an oxygen-free environment. In contrast to modern pyrolyzers that capture the generation of biofuels and syngas, traditional charcoal production using earthen and brick kilns emitted various volatile substances into the atmosphere, leading to air pollution (Zheng et al, 2010). Biochar is a kind of charcoal that has been specifically adapted for agricultural use. Therefore, it is suggested to use BC as a soil amendment to mitigate the effects of anthropogenic climate change and enhance agricultural soil fertility. Biochar is found in soils worldwide as a result of natural occurrences such land clearance by field fires (Krull et al., 2008).

Lehmann and Rondon (2006) showed that biochar is a recalcitrant organic carbon that contains soil micro- and macronutrients. Biochar is refractory organic carbon, including micro- and macronutrients from the soil. The fertility of the Amazon's Terra Preta soils, which have contained charcoal for more than a millennium, exemplifies this exceptional attribute. Unlike other chars, BC primarily consists of a persistent aromatic form of organic carbon that, despite favorable climatic and biological conditions, does not decompose quickly or release carbon dioxide into the environment. As a result, BC may reduce emissions of other greenhouse gases such as nitrous oxide and methane (Sohi et al., 2010). Moreover, biochar offers a different and comparatively safer approach to handling organic waste, along with some added benefits, including the ability to recover energy during pyrolysis from the liquid and gas components (Cely et al., 2015).

### 2.2. Potential uses of biochar

It has been established that BC's interaction with soil bacteria and plant roots begins immediately after application. Biochar has been collected in soils around the globe as a result of natural processes such as land clearance by field fires (Krull et al, 2008). According to Schmidt and Noack (2009) and Novotny et al. (2009), biochar has great stability and resilience to chemical, physical, and biological breakdown. Its chemical makeup, which consists of conjugated polycyclic aromatic rings to create extremely crystalline structures, is what gives it its stability (Mao et al., 2012). Because of this, biochar is more resistant to change and can stay in the environment for a longer period of time than any other type of organic carbon (Lehmann, 2007). Because of its capacity to absorb significant amounts of CO<sub>2</sub> when added to soil, biochar is regarded as a significant carbon sink (Lehmann, 2007). Several investigations have demonstrated the major agronomic advantages of biochar-amended soils,

including higher crop yields. Increases in plant water availability and soil permeability (Asai et al., 2009; Herath et al., 2013), soil cation exchange capacity (Liang et al., 2006; Steiner et al., 2007), neutralization of phytotoxic compounds (Steiner et al., 2007), and soil nutrient retention (Glaser et al., 2002; Lehmann et al., 2003) were all associated with improvements in soil fertility. Char also influences the microbial ecology in the soil and, because it suppresses soil pathogens, may improve plant resilience to disease (Matsubara et al., 2002). The elemental composition of biochar is responsible for all of these benefits because it can directly alter the chemical properties of soil and create a chemically active surface that can catalyze beneficial reactions and alter the dynamics of nutrients. Additionally, biochar's porous structure and large surface area help to alter the physical properties of the soil, which promotes radical development and increases the availability of water and nutrients for plant growth (Matsubara et al., 2002).

### **2.3. Biochar production**

Biochar is an exceptionally stable chemical produced by heating biomass at 350 to 600 degrees Celsius in anaerobic circumstances (Whitman and Lehmann et al., 2009). Biomass is one of the world's most plentiful renewable resources. Despite the availability of other feedstocks, the majority of BC generated in South Africa is derived from agricultural waste such as sugar cane bagasse (Uras et al., 2012). Historically, the majority of agricultural waste was discarded (Duku et al., 2011). Potential biochar's properties are more dependent on the biomass it originated from. Feedstock may be derived from different biomass; agricultural residues such as corn and wheat, yard waste, industrial by-products, animal manure and sewage sludge (Laird et al., 2009). Several techniques for thermally breaking down biomass are used to create biochar, including gasification, hydrothermal conversion, torrefaction, slow pyrolysis, and fast pyrolysis (Meyer et al., 2011). Following pyrolysis, activated charcoal has undergone chemical or steam oxidation (Azargohar, and Dalai, 2006; Raave et al., 2014).

According to Antal and Grønli (2003), activation can enhance surface area and adsorption by eliminating reactive carbon that obstructs pores. As demonstrated by Gaskin et al., (2008) when peanut hull pellets too swelled and blocked the batch reactor, steam activation can be challenging and not suitable for all feedstocks and production temperatures (Laird et al., 2009). The usage of water or steam, the amount of available atmospheric oxygen (O<sub>2</sub>), the rate of heating, the length of time the biomass is in the production chamber or retort, and the temperature are some of the key variations between the various biochar manufacturing techniques (Amonette and Joseph, 2009). Recovery equipment is a type of production gear that is used to power the following batch using the combustible gas produced from the previous batch (Laird et al., 2009).

## 2.4. Biochar physical properties

Potential BC's properties are highly depending on the biomass from which it was formed. Agricultural by products like maize and wheat, as well as yard waste, industrial wastes, animal manure, and sewage sludge, may all be utilised as feedstock (Laird et al, 2009). The environment might be negatively impacted by biochar as well. Soil supplemented with biochar may offer a potential carbon sink (Duku et al., 2011) and help mitigate global warming (Atkinson et al., 2010). Since biochars are made from any type of natural or synthetic organic material and by a variety of procedures (such as gasification and pyrolysis), their characteristics and impacts are highly variable (de Jong et al., 2003). The kind of feedstock (Fushimi et al., 2003), the method of production (Antal and Gronli, 2003), and the process parameters (such as residence time and charring temperature) all have an impact on the physical structure of biochar (Czimczik et al., 2002). We can conclude that understanding physical properties of biochar is essential to address its correct agronomical and environmental uses as well as enabling meaningful pre-application quality assessments, as these properties have a significant impact on the effects of biochar and its interactions with the environment.

### 2.3.1 Biochar chemical properties

Mineral ash makes up around 1-20% of the weight of lignocellulosic biomass, which is composed of nitrogen (N), phosphorus (P), potassium (K), silicon (Si), calcium (Ca), cadmium (Cd), mercury (Hg), and arsenic (As), while extractives make about 1-10% (Duke et al, 2011). High-yield BC is formed when a lignin-rich feedstock is pyrolyzed at high temperatures (Demirbas et al, 2006). As a consequence, biomass with high productivity, such as grasses, is chosen over biomass with low mineral and nitrogen contents. These negative consequences could include N binding and immobilization, the release of some toxic heavy metals associated with biochar, an increase in EC and pH that results in nutrient deficiencies (Singh et al, 2010; Kookana et al, 2011; Xu et al, 2013), or the presence of phototoxic compounds related to plant growth or germination (Rogovska et al, 2012).

Lu and Zhang (2013) have suggested that biochar be used in wastewater treatment to remove heavy metals and other chemicals released by industrial activities. It can also be applied directly to soils to uptake organic and inorganic contaminants, thereby sequestering and making them unavailable for plant uptake (Beesley et al, 2010; This indicates that before applying biochar to soil, some of the undesired effects, like nutrient absorption, increased nutrient leaching, and increased EC, need to be taken into account (Kookana et al., 2011).

## 2.5. Biochar biological properties

Biochar is pulverized charcoal that is added to soil for crop cultivation. The technology's concept is based on the reproduction of Terra Preta. Terra Preta roughly translates to dark earth, and it refers to the process of creating soils that are generally dark in colour, heavy in organic matter, and hence nutrient rich (Glaser et al, 2012). Unlike the previous slash and burn procedures that converted biomass to ash by burning, current biomass undergoes slash and char processes to generate BC Lehmann et al, (2002), which is industrially manufactured through pyrolysis.

Pyrolysis converts labile carbon (C) into relatively stable aromatized carbon, whilst basic cations are transferred from fresh biomass to charcoal (Krull et al, 2009). This is useful because BC, by occupying soil exchange sites, makes these basic cations accessible to the soil when applied to it (Wang et al, 2009). BC, like the Amazon's black carbon-rich Terra Preta soils, should ideally exist in the soil long enough to offer long-term chemical, physical, and biological changes (Hammes, and Schmidt et al, 2009).

## 2.6. Biochar effect on soil nitrogen

Nitrogen is the only limiting nutrient in primary crop yield (Peake et al, 2014). Biochar's absorption into soil modifies nitrogen dynamics by reducing ecologically damaging N-fluxes (Clough and Condron, 2010). Several proposed processes explain the apparent N retention in BC-amended soils and the decrease in nitrogen leaching (Clough et al, 2013). These include  $\text{NH}_3$  or organic-N adsorption on BC, cation or anion exchange processes, and increased N immobilisation as a result of the addition of BC labile C.

Dempster et al, (2010) showed that after 10 weeks of incubation with BC addition at 25 t/ha, net N mineralisation reduced from an average of 11 mg N/kg dry soil to 1 mg N/kg dry soil. The findings did not explain the N sorption to BC at rates of 0, 5, and 25 t/ha. The addition of 20 t/ha of BC to an apple orchard did not significantly alter the mineral-N concentration (Sivakumaran et al, 2010). Wu et al, (2012) reported that BC application decreased  $\text{N}_2\text{O}$  emissions over a 100-day incubation period and field experiment, whereas DeLuca et al. (2010) found that BC application in soil influenced N transformation by enhancing nitrification and N uptake by plants. Before recommending BC application, it is essential to understand how BC application may alter N retention and availability in local soils.

## 2.7. Biochar effect on soil nitrogen processes

### 2.7.1. Mineralisation

Mineralisation is the oxidation of chemical molecules in organic materials, which releases plant-usable nutrients in soluble inorganic forms (White et al, 2005). Mineralisation increases the bioavailability of organic compounds' nutrients, particularly nitrogen, phosphorus, and sulphur. Determining whether the breakdown of an organic compound results in mineralisation or immobilisation is its concentration in respect to the organic component. Mineralisation happens when the concentration of an element surpasses the biosynthetic or storage requirements of the decomposer. McLaren (2012) found that the carbon-to-nitrogen ratio (C: N ratio) of decomposing organic matter affects whether nitrogen mineralizes or immobilises. In general, organic matter-rich soil lacks enough nitrogen to meet the biosynthetic needs of the decomposing microbial community. If the C: N ratio of the decaying organic waste is more than 30:1, the decomposing bacteria may absorb nitrogen in the form of ammonium or nitrate. Pereira et al, (2015) showed that the BC H/C ratio was positively connected with the gross N mineralisation rate and postulated that BC with high H/C ratios will boost mineralisation levels because they are more likely to breakdown and hence release N into the mineral pool. This mineral nitrogen is considered to be immobilised, which may reduce the concentration of inorganic nitrogen in the soil and make nitrogen available to plants. The ratio of carbon to nitrogen in organic matter decreases as carbon dioxide is generated during energy generation during breakdown, a process known as "catabolism." When the C: N ratio is below 25:1, continuous degradation causes mineralization by simultaneously releasing inorganic nitrogen as ammonium (Pereira et al, 2015).

When organic matter decomposes, the mineralized nitrogen is added to the nitrogen already present in the soil, so increasing the overall mineral nitrogen content. According to Yuan. et al, (2010), the cation exchange capacity of BC determines its ability to store  $\text{NH}_4^+$ . Consequently,  $\text{NH}_4^+$  extracted as a measure of N mineralisation may reflect the cation exchange capacity of BC, and vice versa. According to research, BC application to soil either increases, decreases, or has no impact on N mineralisation. In a soil column study, Xu et al. (2010) found that BC application increased net N mineralisation. Similarly, in field study, Pereira et al, (2015) discovered that the addition of BC to an organically managed lettuce farm almost doubled the amount of nitrogen mineralisation compared to the control.

Regardless of soil mixing method, Gundale et al, (2011) discovered that adding wood BC to soil in northern Sweden increased net soil mineralisation levels and  $\text{NH}_4^+$  soil concentrations during two growing seasons. This mismatch was generated more by the increase in net N mineralization than by BC-derived ash (BC is a modest source of  $\text{NH}_4^+$ ). However, Luo et al.

(2016) reported reduced N mineralisation in a coastal wetland soil following BC application. According to Dempster et al, (2010), the reduction in N mineralization was a result of the higher C: N ratio of BC, and the capacity for N mineralization is most likely related to the composition of the BC feedstock. Total net N mineralisation reduced after 18 days of incubation with switchgrass BC applied to an acrisol from Colorado and an alfisol from Virginia. This decrease in mineralisation was attributed to the presence of chemicals such as ethylene, a known nitrification inhibitor, which decreased microbial activity. Prommer et al, (2014) found no significant increase in N mineralisation with little N feedstock BC application. In conclusion, these investigations reveal that the BC feedstock, BC production conditions, time after application, BC capacity to adsorb  $\text{NH}_4^+$ , and soil type must all be considered when assessing the response of soil N to BC mineralisation.

### **2.7.2. Immobilisation**

Immobilisation in soil science refers to the conversion of inorganic elements by microbes or plants into organic molecules, thereby limiting plant access (White et al, 2005). The C/N ratio of plant wastes, according to McLaren (2012), impacts whether nitrogen is mineralised or immobilised. Plant residues that reach the soil often lack enough nitrogen to absorb all of the carbon into their cells for the soil microbial community. The soil microbial community may consume mineral nitrogen if the C: N ratio of decomposing plant material reaches 30:1 (e.g., nitrate). This mineral nitrogen is thought to be immobilised, which might result in a nitrogen deficiency in plants growing in the soil. The C: N ratio of organic matter decreases as a result of breakdown, as does the microbial requirement for mineral nitrogen. When the C: N ratio falls below roughly 25:1, additional breakdown results in simultaneous nitrogen mineralisation that surpasses the expectations of the microbial community. Soil mineral nitrogen will be higher after decomposition due to plant residual nitrogen mineralisation (McLaren et al, 2012).

In terms of N immobilisation, BC studies yield varying results, implying that using incompletely pyrolyzed biomass (rapid pyrolysis at low temperature) may result in soil N immobilisation because growing microorganisms require more N than the substrate provides. Low-temperature BC, in other words, includes more bioavailable C or surface functional groups that may act as microbial substrates (Tibor et al, 2007). Because switch grass has a high C/N ratio, Bruun et al, (2012) conducted a field study using switch grass BC and observed that BC additions to soil improved N immobilisation and total inorganic N in soils. Bruun et al, (2012) also detected a significant increase in cumulative and net  $\text{CO}_2$  flux, suggesting that BC mimicked switch grass mineralisation and accelerated the breakdown of resident soil. According to Jones (2012), increased  $\text{CO}_2$  evolution shortly after BC addition is generated in part by inorganic C emissions from the BC itself. The impact of BC on N immobilisation must

therefore be studied further, with an emphasis on bioavailable C and BC's direct effects on microbial activity.

### **2.7.3. Nitrification**

Nitrification is defined as the biological oxidation of ammonia or ammonium to nitrite, followed by nitrite oxidation to nitrate (Nitrification Network, 2014); the rate-limiting step in nitrification is often ammonia to nitrite conversion. Nitrification is an important stage in the soil nitrogen cycle. Nitrification is an aerobic process in which minute groups of autotrophic bacteria and archaea participate. Nitrification is crucial in agricultural contexts where ammonium-nitrogen fertilisers are routinely utilised. Converting ammonium to nitrate enhances nitrogen leaching because nitrate is more water-soluble than ammonium (Guire et al, 2010). In most soil conditions, there exist species that will complete both phases of the cycle, giving nitrate as the final product. Because nitrate is more water-soluble than ammonia, it improves nitrogen leaching. Nitrification is also significant in nitrogen extraction from municipal sewage. The mineralization process of nitrification and ammonification refers to the complete decomposition of organic material with the release of nitrogen compounds. This contributes to the restoration of the nitrogen cycle (Guire et al, 2010).

The nitrification cycle, which links the ammonification and denitrification cycles, is particularly effective at maintaining nitrogen equilibrium. Moreover, multiple studies have demonstrated that adding BC significantly accelerated soil nitrification and increased soil ammonium-oxidizing bacteria (Nelissen et al, 2012). The addition of charcoal has been shown to enhance the quantity of ammonium-oxidizing bacteria and the rate of nitrification in forest soil (DeLuca et al, 2006). This is explained by the BC adsorption of compounds that inhibit nitrification, such as terpenes and phenols (Ball et al, 2010). Other study, on the other hand, has shown that adding BC to agricultural systems has a considerable inhibitory impact on nitrification, presumably owing to the high nitrification rate (DeLuca et al, 2006) or the presence of a nitrification-inhibiting molecule (-pinene) in the BC (Clough et al, 2010).

### **2.7.4. Leaching**

Leaching is the removal or extraction of certain components from a carrier into a liquid (often, but not always, as a solvent), which may result in the loss of water-soluble plant nutrients from the soil or the use of a small amount of surplus irrigation to avoid soil salinization. Contradictory results have been obtained regarding the sorption of nitrogen (N) by BC derived from various feedstocks and production settings (e.g., pyrolysis temperature). Recent research by Kirehman et al, (2002) has demonstrated that leaching and runoff of N in the forms of  $\text{NH}_4^+$ ,  $\text{NO}_2^-$ , and/or  $\text{NO}_3^-$  would not only reduce the nitrogen utilisation efficiency (NUE) of N fertiliser,

but also cause significant environmental problems such as eutrophication and water biota poisoning. Therefore, enhancing N retention in agricultural soils is crucial (Yao, 2004).

Several further research, according to Gai (2014), showed that BC had little to no capacity to absorb  $\text{NO}_3^-$  and sometimes discharged  $\text{NO}_3^-$  into the environment. According to Joseph (2010), these discrepancies in N sorption results are most likely attributable to the varied physiochemical properties of BC (for example chemical composition, molecular structure, surface area, and porosity). However, the correlations between these properties and their impact on N sorption remain obscure. Despite the development of unique tools for characterising BC, such as Fourier transform-infrared (FT-IR) spectroscopy and scanning electron microscopy (SEM), the essential characteristics for N sorption have not yet been identified. In addition, the impact of feedstock type and pyrolysis temperature on the physiochemical properties of BC are undetermined (Kirehman et al, 2012)

In addition, minimal study has been undertaken on  $\text{NO}_2^-$  sorption using BC despite the toxicity of  $\text{NO}_2$ . Multiple studies have shown that BC may prevent nutrient leaching in agricultural settings. Most cations such as Ca, Mg, K, and Na are conserved because to the cation exchange associated with acidic functional groups produced on BC surfaces during the oxidation process (Gai, 2014). It has been shown that BC's cation exchange capacity (CEC) increases with time in soil and is one of the most important surface chemistry qualities that may improve nutrient retention (Clough et al, 2013). Biochar modifies the composition and physical characteristics of soil solutions, changing the retention of nutrients. Because BC has a higher pH value and is often employed as a liming agent in several agricultural soils, it may indirectly influence soil nutrient solubility through pH variations (Rogvska et al, 2016). Biochar may also alter soil physical qualities such as bulk density, water retention, soil structure, aggregate stability, and total porosity, which affects nutrient retention. Following the addition of pelletised BC, Andrenelli et al, (2006) observed a significant improvement in soil water retention qualities, with total water held in soil pores increasing from 18 to 25% and soil bulk density decreasing, indicating a potential for nutrient retention through reduced water mobility.

## CHAPTER 3: MATERIAL AND METHODS

---

### 3.1. Soil sampling for use in the study

Soil samples were collected at Matavhela Village at latitude  $-22.67276^\circ$  or  $22^\circ 40' 22''$  south; longitude  $30.51862^\circ$  or  $30^\circ 31' 7''$  east; Elevation 887 metres (2.910 feet). Soil samples were obtained at random from depths ranging from 0 to 20 cm using spades and carefully mixed to create a composite sample.

### 3.2. The experiments

The study consisted of two experiments:

Experiment 1 (laboratory experiment): Effect of biochar type and rate of application on leaching and retention of  $\text{NH}_4^+$  and  $\text{NO}_3^-$

Experiment 2 (nursery experiment): Effect of biochar type and rate of application on Maize Biomass accumulation and N Uptake

Both experiments were conducted at the School of Agriculture, University of Venda.

### 3.3 Soil sample analyses

A sub-sample of the air-dried composite sample was sieved through a 2-mm sieve prior to analysis. To characterise the soil, the physical (particle size distribution) and chemical (pH, electrical conductivity, cation exchange capacity, and N, P, K, C, and Mg) parameters of the soil sample were determined. Soil pH and electrical conductivity were measured with a pH metre (Thomas, 1996) and EC metre (Rhoades, 1996) with a soil: water ratio of 1:2.5. Exchangeable cations K, Ca, and Mg were determined using the ammonium acetate extraction procedure; N was determined using the Kjeldahl (Kjeldahl, 1883) method; and P was determined using the Bray No. 1 extract method (Bray, 1948). Bouyoucos' (1936) hydrometer technique was used to evaluate soil texture.

### 3.4. Biochar preparation and characterisation

Poultry manure used in the greenhouse experiment and laboratory was collected from the layers houses, and hay used was collected in the farm at the University of Venda. Poultry litter was made out of a combination of sawdust and chicken dung for bedding. After being allowed to air dry in a clear area, the chicken litter was broken up into small pieces in preparation for pyrolysis. Hay was also allowed to air dry in a clear area and be prepared for pyrolysis. Poultry

litter and hay were pyrolyzed in a kiln furnace that measured 1.4 meters in height and 1.3 meters in width for 60 minutes at 550 degrees Celsius with restricted oxygen. This process produced poultry litter and hay biochar. Lanstar (Pty) (Ltd) provided ready-made acacia biochar that was manufactured at 550°C. To facilitate further study, the chickens and acacia charcoal were crushed and sieved (2.00mm). The pH, Ca, Mg, K of the biochars were examined. According to Aller et al. (2017), the American Society for Testing and Materials (ASTM D1762-84, 2001) changed the analysis for proximate analysis, which included fixed carbon, moisture content, ash content, and volatile matter.

### **3.5. Experiment 1 (Laboratory experiment) set up and design**

Treatments in experiment 1 consisted of a factorial arrangement of three biochar types (acacia, hay, and poultry litter) and three biochar rates of application (0, 1, and 2% w/w), arranged in a completely randomized design and replicated three times. PVC pipes with inner diameter of 12 cm and length of 50 cm were used to build columns with PVC end caps. To enable the soil to dry out and avoid anaerobic conditions, the column tops were left uncovered. A layer of cotton wool was added at the base of each column to keep dirt and BC from falling out, and a thick coating of coarse sand was placed at the bottom of each column to keep soil from falling out. Three kilogrammes of the soil - BC mixture based on treatments stated above were filled into the columns, resulting in an initial bulk density of about 1.5 g/cm<sup>3</sup>. Each column received a single fertiliser treatment of 100 mg ammonium nitrate (NH<sub>4</sub>NO<sub>3</sub>) in solution form. The fertiliser was diluted in 5 ml of distilled water and applied to the surface of each column in equal drips. The columns were kept at room temperature (about 23 °C) in the laboratory.

#### **3.5.1 Leachate collection and analysis**

A funnel positioned above the centre of each column was used every two weeks to supply 200 ml of distilled water to the columns. Filter papers were put on the soil surface of the columns to help disperse the water drips. Throughout the leaching process, the columns were freely drained, and all leachate samples were collected in erlenmeyer flasks wrapped with foil to reduce evaporative loss. Columns were leached every two weeks for ten weeks (70 days). To minimise algal development, the leachates were collected every two weeks and refrigerated before examination. The pH and electrical conductivity (EC) of leachates collected every two weeks were determined. Following that, the leachate samples were filtered using Whatman No 42 filter paper, and ammonium (NH<sub>4</sub><sup>+</sup>) and nitrite (NO<sub>3</sub><sup>-</sup>) levels were determined.

### **3.5.2 Determination of exchangeable inorganic N at the end of the leaching period**

At the end of the leaching experiment after 10 weeks, 250 g of soil in each column was collected, mixed thoroughly, and analysed in triplicate for exchangeable inorganic N ( $\text{NH}_4^+$  and  $\text{NO}_3^-$ ) adsorbed in the soil using the salicylate and Cd-reduction techniques (Mulvaney, 1996)

### **3.6 Statistical analysis**

Analysis of variance (ANOVA) was performed using completely random design (CRD) model and GenStat 64-bit software version 17.1. An ANOVA was used to analyse the impact of BC type and application rate on  $\text{NH}_4^+$ ,  $\text{NO}_3^-$ , pH, and EC. The least significant difference (LSD) at  $P \leq 0.05$  was used to separate the means in cases where there were significant differences between the treatments means.

### **3.7 Experiment 2 (nursery experiment) set up and design**

Pots with a 25 cm height and a 25 cm diameter were used for the experiment. Three different types of BC (acacia, hay, and poultry litter) and three different application rates (0, 1, and 2%) were used as treatments. The pots were filled with 5 kg of soil. All pots received an even application of nitrogen fertiliser (LAN) at a rate of 100 kg N/ha. One week before planting, the BC and ammonium nitrate treatments were applied to the soils. The three replications of the treatments were set up in a completely random design (CRD). Before planting, the pots were wetted and filled to 60% field capacity (FC), then given 24 hours to settle. Per pot, three maize seeds were sown. The pots were watered and brought to 60% field capacity (FC). Maize crops were left to grow up to 8 weeks (56 days), then harvested, dried, weighed, pulverised, and tested for N content and absorption.

#### **3.7.1 Determination of plant parameters**

##### **3.7.1.1 Biomass accumulation**

Plants were sampled 56 days after planting (DAP) to determine biomass accumulation. The samples were oven dried at 70° C for two days or until constant mass was achieved, and thereafter they were weighed to determine biomass weight.

### **3.7.1.2 Plant tissue analysis**

#### **3.7.1.2.1 N concentration**

Samples used to determine biomass were ground and analysed for N concentration. The combustion Kjeldahl method (Kjeldahl, 1883) was used to determine N concentration.

#### **3.7.1.2.2 N uptake**

Nitrogen uptake was determined as the product of N concentration and dry biomass accumulation.

### **3.8 Statistical analysis**

The ANOVA was carried out on the completely random design (CRD) model with the software version 17.1 of GenStat 64-bit. The impact of biochar type and rate of application on biomass accumulation and N uptake was investigated using an ANOVA. When there were significant differences between treatments, mean separation was performed using the LSD at  $P \leq 0.05$ .

## CHAPTER 4: RESULTS AND DISCUSSION

---

### 4.1 Physico-chemical properties of the soil

The initial physico-chemical properties of the soil used in the study are shown in Table 1. The soil is very acidic (pH 3–5) with a very low CEC and a moderate EC, adequate amounts of exchangeable Ca, Mg, and K, and low soil availability of phosphorus. The soil texture is sandy loam.

**Table 1: Physicochemical properties of the soil used in the experiments**

Parameter	Unit	
Sand	%	60.00
Silt	%	22.00
Clay	%	18.00
Textural class	-	sandy loam
pH (KCl)	-	3.50
EC (mS m <sup>-1</sup> )	-	24.91
P	mg/kg	3.00
Na	mg/kg	2.00
K	mg/kg	14.00
Ca	mg/kg	271.00
Mg	mg/kg	88.00
CEC	Cmol (+)/kg	3.30
NH <sub>4</sub> <sup>+</sup>	mg/g	13.09
NO <sub>3</sub> <sup>-</sup>	mg/g	2.33

## 4. 2 Chemical composition of acacia, poultry litter, and hay biochar

The chemical composition of acacia, poultry litter, and pine wood BC used in the study is presented in Table 2. The acacia BC had an alkaline pH (9, 23), with low total N and available P. The acacia BC had a high CEC and low Ca, Mg, and K content. The poultry litter BC had alkaline pH (10.30), with low total N and moderate available P. The poultry litter BC contained high amounts of Ca, Mg, and K with a high CEC. The hay BC had an alkaline pH of 8 (51), with low total N and available P. The hay BC had a high CEC and a moderate amount of Ca, Mg, and K content.

**Table 2: Chemical composition of three different biochar types (acacia, poultry litter and hay) used in the study**

Parameter	Acacia Biochar	Poultry Biochar	Hay Biochar
pH	9.23	10.30	8.51
EC (mS/m)	40.00	58.93	37.95
Ash (mg/kg)	164.00	170.00	157.01
C in Ash (mg/kg)	45	54	38
Moisture (%)	6.66	7.70	4.52
Total C %	56.70	56.00	54.00
Total N %	1.03	3.11	0.83
C/N Ratio (g/g)	55.10	18.1	20.35
CEC (Cmol <sub>(+)</sub> /kg)	124.71	442.7	234.91
Available P (mg/kg)	0.50	24.00	12.11
K (mg/kg)	5.10	40.10	4.10
Ca (mg/kg)	18.40	32.00	20.13
Mg (mg/kg)	2.22	16.20	8.90

### **4.3. Experiment 1**

#### **4.3.1 Total amount of leachate collected after leaching interval**

The kind of biochar, the rate at which it was applied, and the interaction between biochar type and application rate all had a significant impact on the quantity of leachates ( $P < 0.01$ ) (Table 3). Enhancement of the physical properties of the soils, leading to increased water retention and acquisition (Atkinson et al., 2010). The quantity of leachate collected was much greater when chicken litter biochar was used compared to the other two forms of biochar. In their study, Glab et al. (2016) found that using poultry biochar led to an increased moisture content during sampling. This finding supports the results drawn from previous short-term and laboratory trials. Compared to other types of soil organic matter, it exhibited greater porosity and surface functioning, which provided a valid justification for this. No significant difference was seen in the quantities of leachate collected when biochar was applied at rates of 1% and 2%. In comparison to the control group (0%), the quantity of leachates collected rose by 46% and 42% at the application rates of 1% and 2% BC, respectively (Table 3).

**Table 3: Total amount of leachate (ml) collected after leaching interval**

<b>Biochar Type</b>	<b>Amount of leachate</b>
Hay Biochar	66.89 <sup>c</sup>
Poultry Biochar	90.36 <sup>a</sup>
Acacia Biochar	76.44 <sup>b</sup>
SEM	2.37
<b>Rate of Application</b>	
0%	51.03 <sup>b</sup>
1%	94.22 <sup>a</sup>
2%	88.40 <sup>a</sup>
SEM	2.39
<b>F-Test Probability</b>	
Biochar Type (BT)	**
Rate of Application (RA)	**
BT x RA	**

\*\* :  $P < 0.01$ ; (ns) not significant:  $P > 0.05$ .<sup>abc</sup> Column means with different superscripts differ significantly at  $P < 0.05$ . N:  $\text{NH}_4^+$ : ammonium,  $\text{NO}_3^-$ : Nitrate and SEM: Standard Error Mean.

#### 4.3.2 Effect of biochar type on concentration of $\text{NH}_4^+$ leached during the 70-day period

The kind of biochar had a substantial impact ( $P < 0.01$ ) on the leached concentration of  $\text{NH}_4^+$  as seen in Figure 1. The use of chicken litter BC resulted in a gradual reduction in the leached  $\text{NH}_4^+$  concentration from the first day to the seventieth day of the leaching period. On the fourteenth day, the amount of  $\text{NH}_4^+$  that was washed out was roughly 94% more compared to the amount washed out from the hay and acacia biochar treatments. According to Adeliet et al. (2009), chicken litter has been shown to enhance the organic matter content of soils, as well as improve water retention, increase the penetration of oxygen into the soil, and enhance soil aggregation. Contrary to nitrate, the capacity of BC to attract ammonium seems to be unaffected by the temperature at which it is produced and is also influenced by the kind of material used as a source (Clough et al, 2013). The leaching of  $\text{NH}_4^+$  exhibited its maximum concentration during the first 14-day period. Subsequently, there was a fall in concentration from day 14 to day 42, followed by a little rise on day 56. However, following the application of chicken litter, there was a further decline in concentration until day 70.

There was no discernible disparity in the quantity of  $\text{NH}_4^+$  leached between the hay and acacia BC treatments from day 14 to day 42. On day 56, the use of acacia BC resulted in a modest rise in the  $\text{NH}_4^+$  content, as compared to hay BC. Having a wide surface area of biochar (BC) provides agricultural advantages as it improves the ability of soil to retain water (along with nutrients) when applied to soil that is abundant in macrospores (Glaser et al., 2002). Studies conducted by Oh et al. (2004), Oh and Chiu (2009), Oh et al. (2012), and Klüpfel et al. (2014) have shown that black carbons and BCs possess redox reactivity and may operate as catalysts in the reduction of various organic and nitrogenous chemicals. The reduction in redox reactivity is ascribed to the condensed aromatic ring structures of BC, which enhance electron transfer activities (Oh et al, 2012). The leaching of nitrogen, both in organic and inorganic forms, may have been reduced by the presence of charcoal. While leaching is likely the primary cause of nitrogen loss in the soil being studied, this research was unable to identify the exact amount. The rise, however, was short-lived as the  $\text{NH}_4^+$  content quickly decreased until day 70 in all BC treatments (Fig 1).

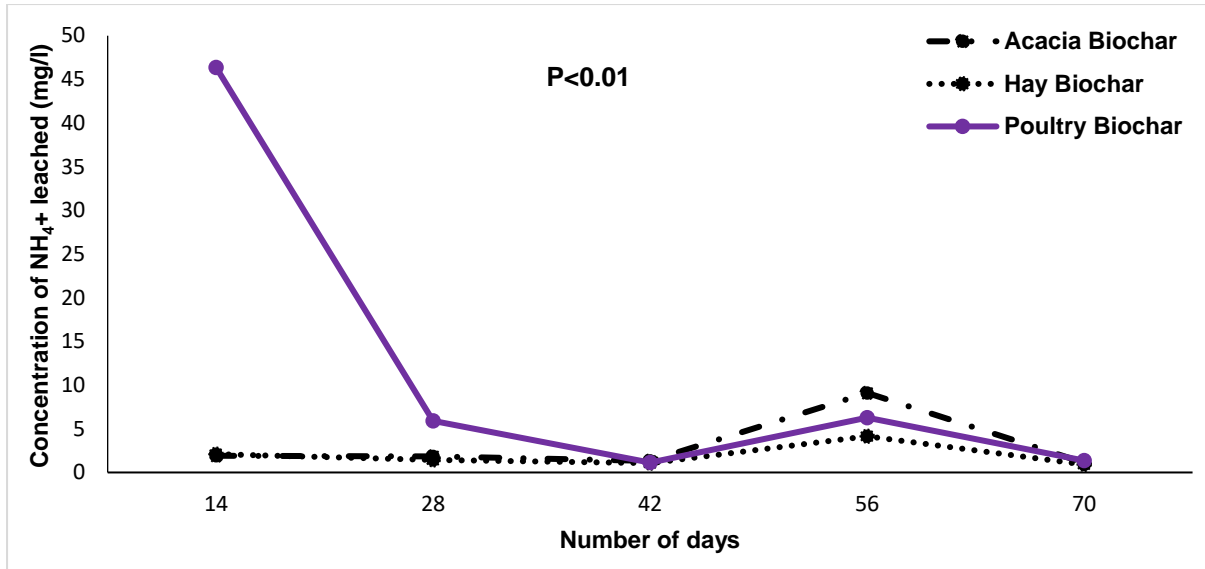


Figure 1: Effect of biochar type on concentration of ammonium leached after (70) days

### 4.3.3 Effect of biochar application rate on concentration of $\text{NH}_4^+$ leached during the 70-day leaching period

The application rate of biochar had a significant impact ( $P < 0.01$ ) on the concentration of  $\text{NH}_4^+$  that was washed away on various days (Fig. 2). After a duration of 14 days, the concentration of leached ammonium was found to be greater at a concentration of 2% (31.39 mg/l) and 1% (16.02 mg/l) compared to the control. In a study conducted by Wang et al. (2015), it was discovered that the addition of 2% and 4% biochar resulted in a decrease in leached  $\text{NH}_4^+$  to levels of 2.59 and 3.56 mg/kg, respectively. Between day 15 and day 42, there was a progressive drop in the concentration of  $\text{NH}_4^+$ . After that, there was a little rise until day 56, followed by another decline until day 70. On the 56th day, the amount of  $\text{NH}_4^+$  that was washed away was greater in the control group and the group treated with 1% biochar compared to the group treated with 2% biochar (Fig 2). Recent research has shown that biochar has the ability to absorb nutrients from fertilisers and then release them in a controlled way at times. Ding et al. (2016) said that biochar's characteristic makes it a viable option for use as a slow-release fertiliser. This might be advantageous in terms of mitigating nutrient losses via leaching in agricultural systems.

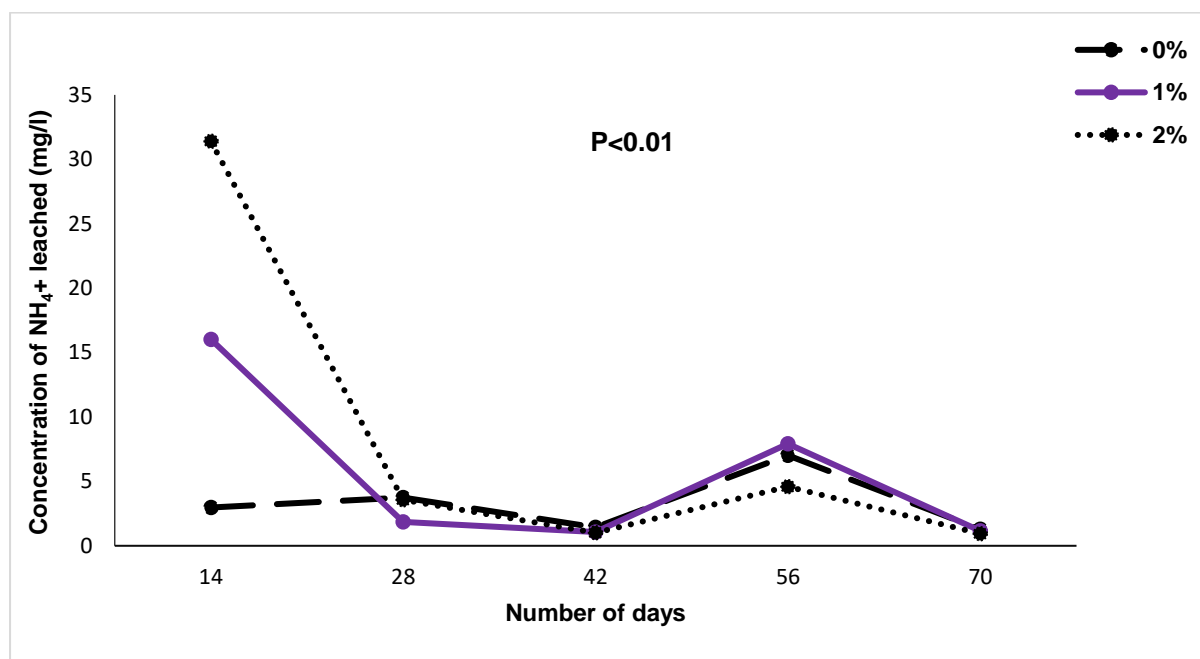
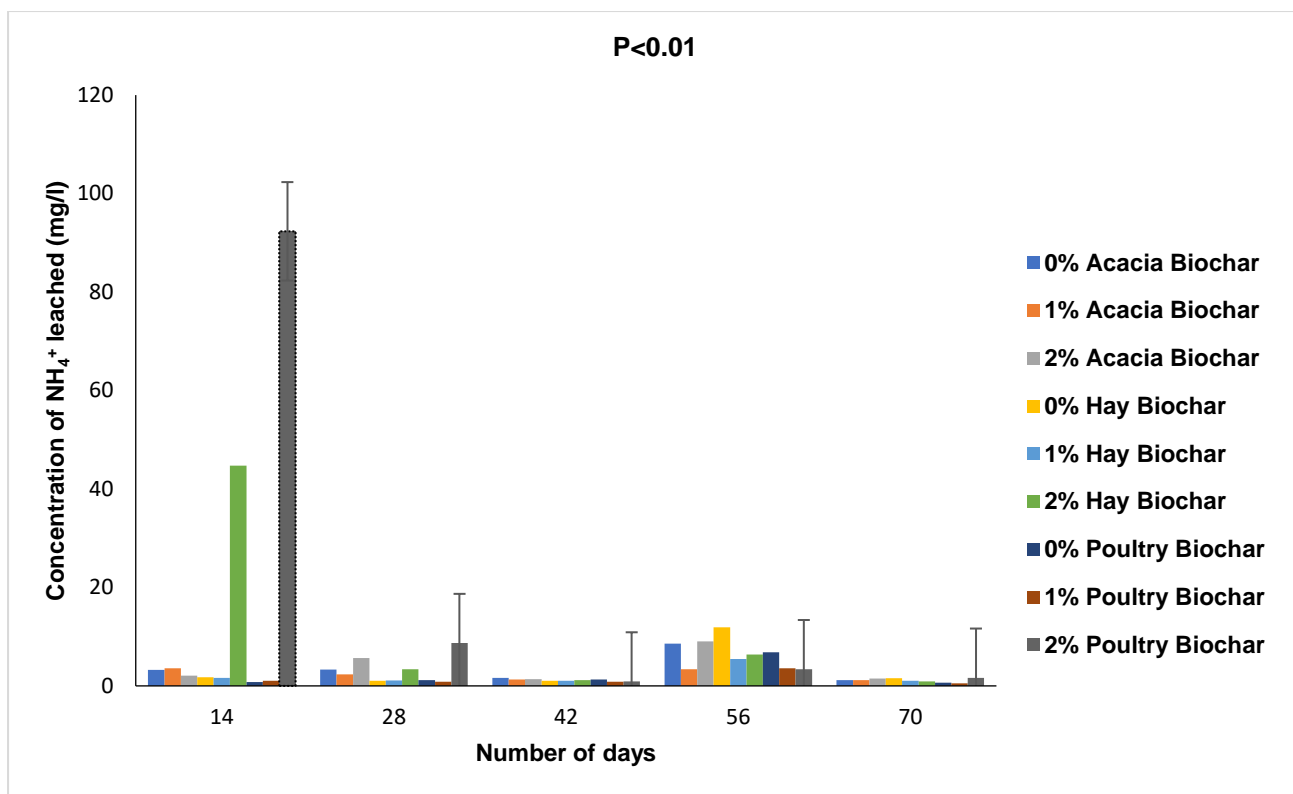


Figure 2: Effect of rate of application on concentration of ammonium leached during the 70-day leaching period

#### 4.3.4 Interactive effect of biochar type and rate of application on concentration of ammonium leachate during the 70-day leaching period

An interaction impact of biochar type and application rate of biochar on the concentration of  $\text{NH}_4^+$  over the 70-day leaching period was observed, and this effect was statistically significant ( $P < 0.01$ ) (Fig. 3). The leaching of  $\text{NH}_4^+$  from the 2% poultry litter BC treatment was 92.33 mg/l more than that of the control and other BC treatments on day 14. This suggests that soils enriched with acacia and hay biochar types had a higher retention of nutrients. Soils treated with Acacia BC had the lowest level of water leaching. In a study conducted by Sika (2014), it was shown that the application of acacia BC to a sandy soil in South Africa resulted in a decrease in the leaching of ammonium and nitrate. However, it was also seen that the levels of exchangeable ammonium and nitrate were decreased, indicating that the nutrients may have been absorbed into the pores of the BC. On days 28 and 42, there was no discernible disparity in the quantity of  $\text{NH}_4^+$  leached between the hay and acacia BC treatments, regardless of the biochar application rates. When comparing all BC types, the use of all BC resulted in a little rise in the concentration of  $\text{NH}_4^+$  on day 56. The results indicate that electrostatic adsorption takes place at exchange sites and reduces N leaching resulting from the impact of applied  $\text{NH}_4^+$  (Steiner et al., 2008). BC, with its adsorption capabilities and ability to inhibit the gradual nitrogen loss, has the potential to serve as a soil supplement for nutrient retention. The concentrations of  $\text{NH}_4^+$  then exhibited a fast decline across all application rates by day 70 (Fig 3). Laird et al. (2010) proposed that the cause of this phenomenon is the larger surface areas and the presence of denitrifying bacteria, which leads to a decrease in  $\text{NH}_4^+$  levels as a result of the wetness in the leaching columns. Furthermore, it is believed that the reduced carbon-to-nitrogen ratio of poultry litter BC enhanced microbial activity, leading to a temporary immobilisation of nitrogen, as shown by Lehmann et al. (2003).



**Figure 3: The interactive effects of biochar type and rate of application on concentration of ammonium leachate during the 70-day leaching period.**

#### 4.3.5 Effect of biochar type on concentration of $\text{NO}_3^-$ leached during the 70-day leaching period

The impact of the kind of biochar on the concentration of leached  $\text{NO}_3^-$  was not statistically significant during the 70-day leaching period, as shown in Figure 4. Nevertheless, the biochar made from chicken litter consistently showed greater amounts of  $\text{NO}_3^-$  for the whole 70-day leaching period.

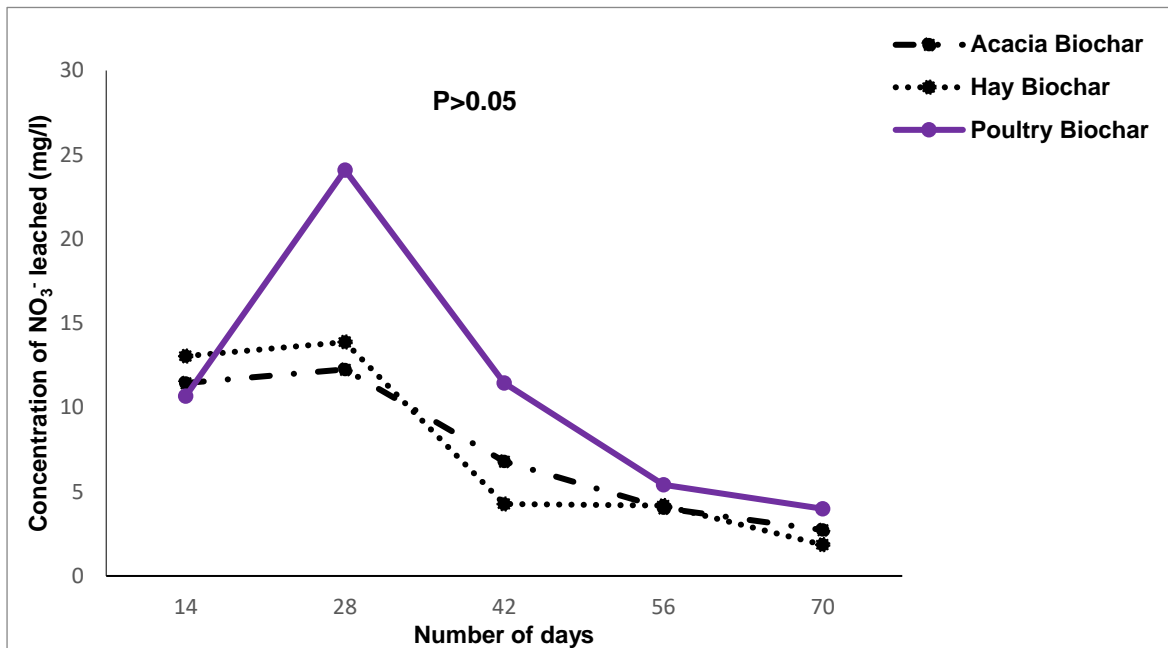


Figure 4: Effect of biochar type on concentration of  $\text{NO}_3^-$  leached during the 70-day leaching period

#### 4.3.6 The effect of biochar rate of application on concentration of $\text{NO}_3^-$ leached during the 70-day leaching period.

There was no notable impact on the concentration of nitrate leached over the 70-day leaching period, regardless of the rate at which biochar was applied (Fig. 5). Each treatment showed a consistent pattern of an initial rise in  $\text{NO}_3^-$  concentration from day 14 to 28, followed by a subsequent decrease in  $\text{NO}_3^-$  concentration until day 70.

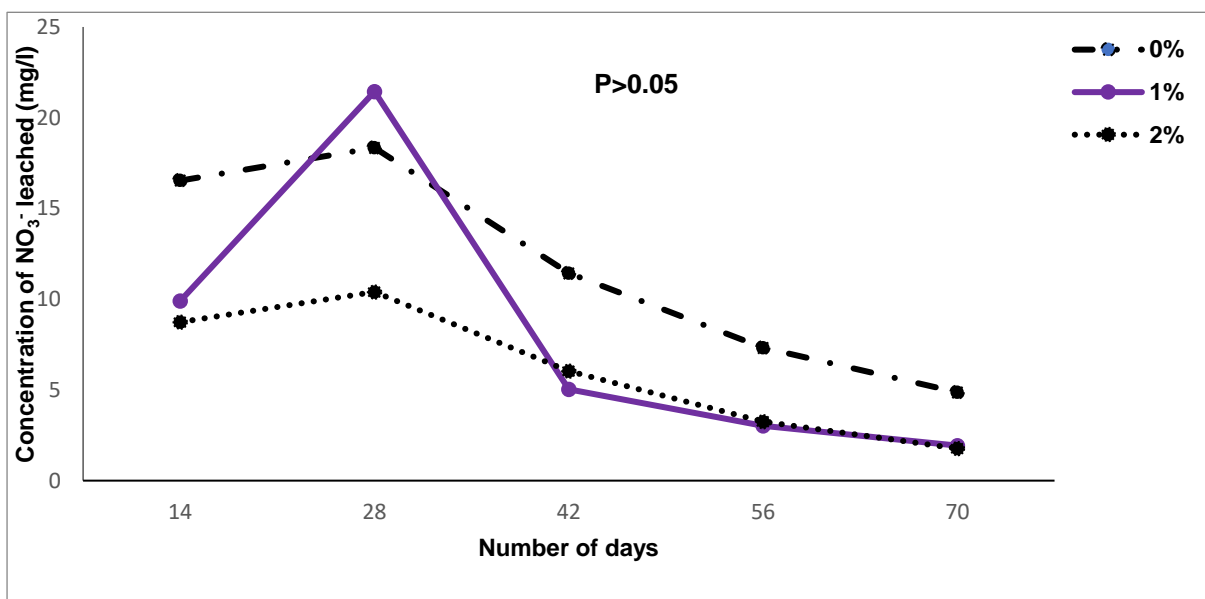
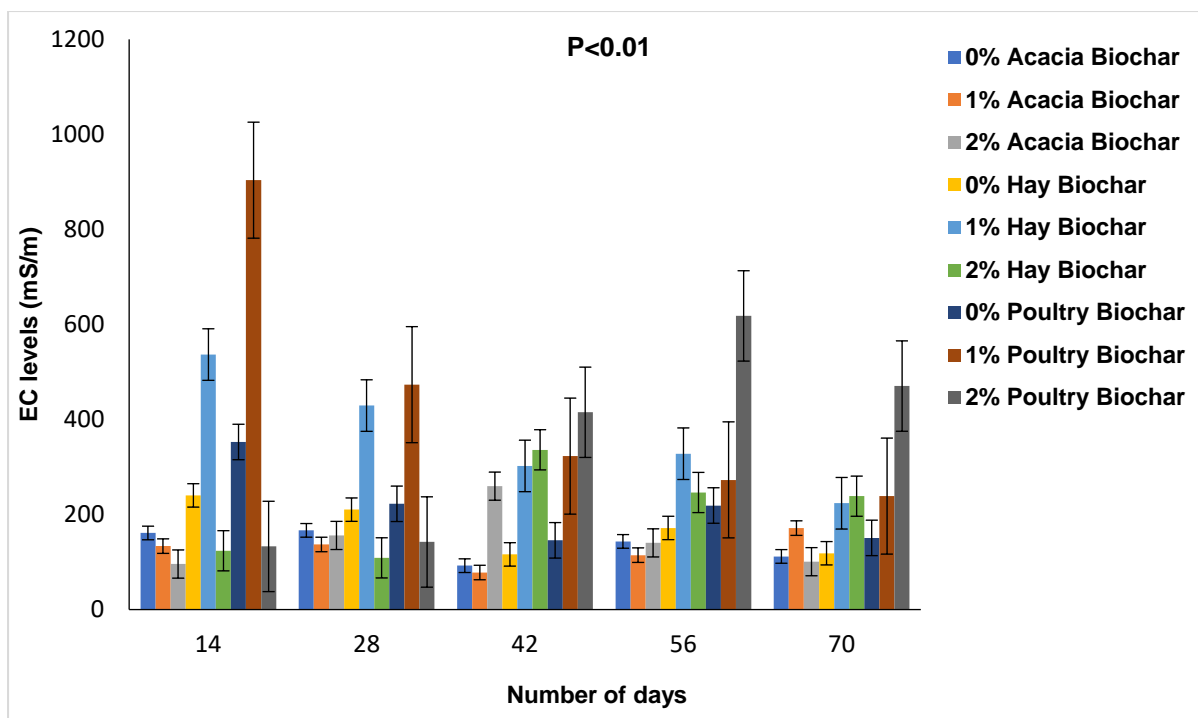


Figure 5: Effect of rate of application on  $\text{NO}_3^-$  concentration during the 70-day leaching period.

#### **4.3.7 Interactive effect of biochar type and rate of application on Electrical Conductivity (EC) of leachate during the 70-day leaching period**

At both the 14-day and 28-day time points, the 1% poultry and hay BC treatments exhibited the greatest electrical conductivity (EC) levels, in comparison to the 2% treatment and the control. Conversely, the 1% acacia treatment had lower EC levels than the control (Fig.6). After 42 days, the EC (electrical conductivity) of the 2% treatments was higher than that of the 1% treatments and the control. The poultry BC treatment with a concentration of 2% consistently showed higher EC (electrical conductivity) levels compared to the treatment with a concentration of 1% and the control group at both 56 and 70 days. Regarding the treatment of acacia BC, there was no discernible variation in EC (electrical conductivity) between the 1% and 2% treatments after 56 days. However, after 70 days, the 1% acacia BC therapy exhibited a considerably greater EC compared to both the 2% treatment and the control group.

The electrical conductivity (EC) values exhibited fluctuations starting from day 56 and consistently stayed at a low level until the conclusion of the leaching period. In their study, Ding et al. (2010) discovered that soil columns containing 0.5% biochar (BC) and nitrogen (N) delivered as ammonium chloride exhibited reduced electrical conductivity (EC) in the leachate. Given the established understanding that both irrigation and rainfall progressively eliminate salts from soil, it was anticipated that the observed electrical conductivity (EC) would decrease with time for all treatments. From day 56 to 70, there was a decrease of 2% in the poultry litter. Subsequently, the 1% hay BC treatment consistently displayed a greater EC (Electrical Conductivity) compared to both the 2% treatment and the control. However, there was no statistically significant difference seen between the 1% and 2% treatments. The observed increase in organic carbon intake from BC is likely responsible for this phenomenon. Interestingly, acacia biochar, regardless of the treatment rate, exhibited reduced electrical conductivity (EC) when compared to hay and poultry BC.



**Figure 6: Interactive effects of biochar type and rate of application on leachate EC during the 70-day leaching period.**

#### **4.3.8 Nitrate ( $\text{NO}_3^-$ ) and ammonium ( $\text{NH}_4^+$ ) retention at the end of the 70-day leaching period**

The kind of biochar had a noteworthy impact on nitrate retention ( $P < 0.01$ ), while the application rate had a notable impact on both ammonium and nitrate retention in the soil under investigation (Table 4). The application of poultry and hay biochar (BC) led to a considerably greater nitrate retention in the soil under study compared to acacia BC. BC's ability to absorb  $\text{NO}_3^-$  from aqueous solutions (Zheng et al, 2013) might be a contributing factor to the decrease in  $\text{NO}_3^-$  leaching. The results indicate that columns containing a mixture of biochar saw a lower leaching of components. This suggests that the reduction in leaching is a result of incorporating biochar. Therefore, it is essential to effectively control the electrical neutrality of the soil solution system in order to comprehend the movement of nutrients at a fundamental level. To do this, it is necessary to ensure that the movement of anions is accompanied by the movement of cations (Major et al, 2005).

Applying 2% BC led to a significant increase in the retention of  $\text{NH}_4^+$  and  $\text{NO}_3^-$  compared to the control and 1% BC. 2013. Biochar has the ability to retain  $\text{NH}_4^+$  in soils by undergoing cation exchange through acid functional groups (such as carboxyl and hydroxyl) on its surface. However, the cation exchange capability of fresh biochar is limited and varies depending on the feed stocks and production circumstances. BC, with its adsorption qualities and ability to reduce nitrogen leaching losses over time, has the potential to serve as a soil supplement that

effectively maintains nutrients. The reduction in  $\text{NH}_4^+$  leaching from the soil modified with BC, without any other substances, may be attributed to the adsorption of  $\text{NH}_4^+$  on the BC. Regarding the  $\text{NH}_4^+$  ion, there was no discernible disparity in retention between the 1% treatment and the control. However, in the case of  $\text{NO}_3^-$ , the 1% treatment exhibited a considerably greater level of  $\text{NO}_3^-$  retention compared to the control. Biochar has the potential to modify the conversion of nitrogen in soils, leading to reduced nitrogen loss, as well as decreased leaching and increased absorption of ammonium and nitrate ions (Ball et al, 2010; Clough and Condrón, 2010). The application of BC at a concentration of 2% resulted in  $\text{NH}_4^+$  retention rates that were 14.9% and 6.1% greater than the control and 1% treatment, respectively. Additionally, the  $\text{NO}_3^-$  retention rates were 83.6% and 42.1% higher than the control and 1% treatment, respectively. Based on the study results, BC, which is a very effective ion adsorbent, has the potential to greatly reduce the leaching of easily movable nutrients like nitrate from fertilisers in sandy loam soils. This might lead to a temporary immobilisation of nitrogen, resulting in a nitrogen deficiency.

**Table 4: Effect of biochar type and rate of application on nitrate and ammonium retention at the end of the 70-day leaching period.**

<b>Biochar Type</b>	<b><math>\text{NH}_4^+</math> Concentration (mg/l)</b>	<b><math>\text{NO}_3^-</math> Concentration (mg/l)</b>
Hay Biochar	8.82	4.30 <sup>a</sup>
Poultry Biochar	8.83	4.73 <sup>a</sup>
Acacia Biochar	8.78	2.57 <sup>b</sup>
SEM	0.15	0.19
<b>Rate of Application</b>		
0%	8.07 <sup>b</sup>	2.81 <sup>c</sup>
1%	8.74 <sup>b</sup>	3.63 <sup>b</sup>
2%	9.27 <sup>a</sup>	5.16 <sup>a</sup>
SEM	2.39	0.19
<b>F-Test Probability</b>		
Biochar Type (BT)	ns	**
Rate of Application (RA)	**	**
BT x RA	Ns	Ns

\*\* :  $P < 0.01$ ; (ns) not significant:  $P > 0.05$ . abc Column means with different superscripts differ significantly at  $P < 0.05$ .

,  $\text{NH}_4^+$ : ammonium,  $\text{NO}_3^-$ : Nitrate and SEM: Standard Error Mean

## 4.4 EXPERIMENT 2

---

### 4.4.1 Biomass accumulation and N uptake

The kind and application rate of biochar had a notable impact on the build-up of biomass ( $P < 0.05$ ) and the absorption of nitrogen ( $P < 0.01$ ) (Table 5). The use of poultry biochar resulted in enhanced biomass build-up. The rate of application of 2% resulted in a 48.83% increase in biomass build-up and a 58.28% increase in N absorption. The application rate of chicken litter BC, followed by hay BC and acacia BC, used in this study was likely sufficient to enhance the biomass accumulation of the maize plant. The use of biochar has been shown to improve the growth of biomass in both controlled and natural environments (Blackwell et al, 2009). According to Steiner et al. (2007), there is evidence of a progressive increase in the favourable effects of BC over time. Their study suggests that applying BC to soil might lead to long-term benefits. Cornelissen et al. (2013) and Smider and Singh et al. (2014) provided evidence that the application of 40 t/ha of BC resulted in improved dry matter and yield in several crops.

Glaser et al. (2002) conducted study on the impact of BC on soil health and agricultural productivity. They studied various soil types and management practices, yielding diverse outcomes. The application of poultry litter biochar resulted in an estimated dry biomass output of 27g, whereas hay biochar produced 18g and acacia biochar gave 15g, respectively. The use of BC was influenced by agricultural methods, crop type, climatic circumstances, and fertilisation, which in turn affected the responses of plants and soil. The results, however, suggest that using BC at a rate above 2 t/ha might potentially enhance the biomass yield of maize plants. Nevertheless, field experiments may be required to ascertain the ideal treatment rate for achieving maximum biomass production.

### 4.4.2 Effect of biochar type and rate of application on N uptake of maize

The pace of biochar application has an impact on the absorption of nitrogen. The current study revealed that the application of BC at a rate of 2% led to a significant increase in nitrogen absorption, with a value of 254.1 g/kg. This was followed by 199.95 g/kg at a rate of 1%, and 106.22 g/kg at a rate of 0%. These findings are summarised in Table 5. Uzoma et al. (2011) reported a significant increase in nutrient absorption after the application of biochar, which was likely due to the use of biochar made from cow dung as the source material. The study saw a significant uptake of nitrogen. However, the extent of absorption may vary depending on the specific BT employed. In this case, chicken dung feedstock was used, which mineralizes at a slower rate compared to other feedstocks. Consequently, it will take longer time for nitrogen to be taken up. Based on the abundance of nutrients in the soil, Uzoma et al, (2011) proposed that a moderate amount of BT application (15 to 20 t/ha) might potentially have a positive effect on the soil and enhance nutrient uptake. Unlike the previous study, the

application of 2% BT had a positive effect and enhanced the absorption of nutrients, perhaps due to the increased availability of nutrients in the soil. Given that N uptake values were determined based on dry matter yield and N content, the N uptake values exhibit a comparable trend to biomass yield.

The increase observed from a 0% to 2% rate can be attributed to the release of Biochar Type nutrients (both cations and anions) that are loosely bound, into the soil solution. This makes them readily available for absorption by plants. Thus, the decrease in nitrogen absorption is caused by the small proportion of black carbon that may easily be converted into minerals, leading to nitrogen immobilisation (Chan and Xu, 2009). This is particularly crucial since the remaining nitrogen in charcoal is mostly composed of refractory heterocyclic nitrogen rather than accessible amine nitrogen (Cao et al., 2009; Novak et al., 2009). The combined influence of biochar type and application rate did not have a significant impact on the build-up of biomass and absorption of nitrogen. In this research, it was shown that different soil-BC mixes showed restricted nitrogen uptake when no fertiliser was supplied. Consequently, the growth was limited when the acacia BC treatment amount was 0 t/ha. Nevertheless, considering the elevated nitrogen concentration in the plant, it is improbable that the reduced growth may be attributed to insufficient nitrogen absorption.

**Table 5: Effect of biochar type and rate of application on biomass accumulation and N uptake**

<b>Biochar Type</b>	<b>Biomass (g/kg/plant)</b>	<b>N uptake (g/kg/plant)</b>
Hay Biochar	8.02 <sup>b</sup>	157.54 <sup>ab</sup>
Poultry Biochar	27.91 <sup>a</sup>	265.83 <sup>a</sup>
Acacia Biochar	14.50 <sup>ab</sup>	137.40 <sup>b</sup>
SEM	3.17	23.50
<b>Rate of Application</b>		
0%	12.88 <sup>b</sup>	106.22 <sup>b</sup>
1%	22.04 <sup>ab</sup>	199.95 <sup>ab</sup>
2%	25.17 <sup>a</sup>	254.61 <sup>a</sup>
SEM	3.17	23.50
<b>F-Test Probability</b>		
Biochar Type (BT)	*	**
Rate of Application (RA)	*	**
BT x RA	ns	ns

\*\* : P<0.01; (ns) not significant: P >0.05.abc Column means with different superscripts differ significantly at P <0.05 and SEM: Standard Error Mean

## CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

---

### 5.1 Conclusion

The results of experiment 1 demonstrate that the utilisation of BC may effectively decrease the leaching of highly mobile nutrients such as  $\text{NH}_4^+$  and  $\text{NO}_3^-$ . The quantity of leachates collected had a 46% and 42% rise at the 1% and 2% biochar application rates, respectively. The retention of ammonium and nitrate rose by 1.62% and 16.2% respectively, when applied at a rate of 2%. When compared to the control group, where no BC was applied, the addition of BC considerably decreased the leaching of ammonium by 1% on days 56-70 and by 2% (w/w) in soils modified with BC. Biochar increased electrical conductivity (EC) levels in all biochar treatments (BT) and effectively retained ammonium ions ( $\text{NH}_4^+$ ) and nitrate ions ( $\text{NO}_3^-$ ). Therefore, the findings indicate that BC has the potential to decrease the overall leaching of nitrogen over a period of time and at higher concentrations. In addition, although BC may have a decreasing influence on the leaching of inorganic N from soils, it is not able to effectively reduce leaching in the short term since not all nitrates were leached by the end of the ten-week study.

Experiment 2 has shown that the kind of feedstock had a significant effect on the build-up of biomass and the absorption of nitrogen. Application of chicken litter, hay, and acacia BC resulted in higher maize biomass build-up and nitrogen absorption, respectively. Nevertheless, the formation of BC biomass was reduced when no fertiliser was administered, namely at 0% (control). The use of biochar had an impact on the absorption of nitrogen. The use of biochar had a favourable effect on nitrogen absorption, resulting in improved plant production. In order to assess and measure the lasting agronomic and environmental impacts of biochar on agricultural soils, it is necessary to conduct field trials.

### 5.2 Recommendations

According to this study and other research, biochar has the capacity to enhance soils with different textures. Given that the properties of biochar (BC), such as pH and nutrient availability, are influenced by the feedstock and pyrolysis conditions used to produce it, it is advisable to do research on various pyrolysis procedures using diverse feedstocks in order to generate BC suitable for soil application. Additional research using the same biochars used in this study, but with modified rates, might be undertaken to ascertain the optimal rates for utilising them as a soil amendment for nitrogen control. Given the constraints of conducting this research in a controlled setting, such as limited temperature and moisture conditions, it is advisable to carry out field experiments in order to get definitive findings about the use of BC as a soil amendment. Lastly, research may include various soil types and biochar derived from diverse feedstocks.

## REFERENCES

---

1. Adeliel KL, Jones DLL, Murphy DVV, and Khalid M (2009) Short-term biochar-induced increase in soil CO<sub>2</sub> release is both biotically and abiotically mediated. *Soil Biology and Biochemistry* 43(8):1723–1731.
2. Aller PM, Yang Y, Qiu R (2017) Characterization of sewage sludge-derived biochars from different feedstocks and pyrolysis temperatures. *Journal of Analytical Applied Pyrolysis* 102:137–143.
3. Amonette JE, and Joseph S (2009) Characteristics of biochar microchemical properties. In *Biochar for environmental management: science and technology*. Eds. Earthcan 33-52.
4. Andrenelli MC, Maienza A, Genesio L, Miglietta F, Pellegrini S, Vaccari FP, Vignozzi N (2006) Field application of pelletized biochar: short-term effect on the hydrological properties of a silty clay loam soil. *Agricultural Water Management* 163:190–196.
5. Antal MJ, and Grønli M (2003) The art, science, and technology of charcoal production. *Indigenous*. English. *Chemistry Research* 42(8): 1619–1640.
6. Atkinson CJ (2010) Potential mechanisms for achieving agricultural benefits from biochar applications to temperate soils: A review. *Plant Soil* 337: 1–18.
7. Asai H, Samson BK, Stephan HM, Songyikhangsuthor K, Homma K, Kiyono Y, Inoue Y, Shiraiwa T, Horie T (2009) Biochar amendment techniques for upland rice production in Northern Laos 1. Soil physical properties, leaf SPAD and grain yield. *Field Crops Research* 111:81–84
8. Azargohar R, and Dalai AK (2006) Biochar as a precursor of activated carbon. *Applied Biochemistry and Biotechnology* 129-132: 762–773.
9. Ball PN, MacKenzie MD, DeLuca TH, and Montana WE (2010) Wildfire and charcoal enhance nitrification and ammonium-oxidizing bacterial abundance in dry montane forest soils. *Journal of Environmental Quality* 39(4):1243-1259.
10. Beesley L, Moreno-Jimenez E, Gomez-Eyles JL (2010) Effects of biochar and green waste compost amendments on mobility, bioavailability and toxicity of inorganic and organic contaminants in a multi-element polluted soil. *Environmental Pollution* 158:2282–2287
11. Blackwell PE, Krull G, Butler A, Aust Herbert, and Solaiman Z (2009) Effect of banded biochar on dry land wheat production and fertiliser use in south-western Australia. An agronomic and economic perspective. *Soil Respiration* 48(7): 531–545.
12. Bray H. G, Lake HJ, Neale F C, Thorpe WV, and Wood PB (1948). Determination of total, organic, and available forms of phosphorus in soils. *Biochemistry Journal* 42-434.

13. Bouyoucos GJ (1936) Hydrometer method improved for making particle size analyses of soils. *Agronomy Journal* 54:464–465.
14. Bruun EW, Ambus P, and Egsgaard H (2012) Effects of slow and fast pyrolysis biochar on soil C and N turnover dynamics. *Soil Biology and Biochemistry* 46:73–79.
15. Camargo JA, and Alonso A (2006) Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems. A global assessment. *Environmental Introduction* 32: 831–849.
16. Cao HC, et al. (2009) Potential Ecological Risk of Cadmium, Lead and Arsenic in Agricultural Black Soil in Jilin Province, China. *Stochastic Environmental Research and Risk Assessment*, 23: 57-64.
17. Cely, P, Gascó G, Paz-Ferreiro J, M´endez A (2015) Agronomic properties of biochars from different manure wastes. *Journal of Analytical and Applied Pyrolysis. Using poultry litter biochars as soil amendments. Soil Research* 46:437–444.
18. Chan KY, Xu Z, Lehman J, and Joseph S (2009) Biochar. Nutrient properties and their enhancement. In *Biochar for environmental management: science and technology* 38:67-84.
19. Choudhury AT, and Kennedy IR (2005) Nitrogen Fertilizer Losses from Rice Soils and Control of Environmental Pollution Problems. *Communications in Soil Science and Plant Analysis* 36:1625-1639.
20. Clough TJ, Condon LM, O’Callaghan M, Sherlock RR, and Wells NS (2010) Unweathered wood biochar impact on nitrous oxide emissions from a bovine-urine-amended pasture soil. *Soil Science Society of American Journal* 74(3):852-957.
21. Clough TJ, Condon LM, Kammann, C, and Müller C (2013) A review of biochar and soil nitrogen dynamics. *Agronomy* 3:275–293.
22. Cornelissen JH, Amatangelo K, Dorrepaal E, Eviner VT, Godoy O (2013) Plant species traits are the predominant control on litter decomposition rates within biomes worldwide. *Ecology Letters* 11: 1065–1071.
23. Czimczik CI, Preston CM, Schmidt MWI, Werner RA, Schulze ED (2002) Effect of charring on mass, organic carbon, and stable carbon isotope composition of wood. *Organic Geochemistry* 33:1207–1223.
24. De Jong W, Pirone A, Wójtowicz MA (2003) Pyrolysis of *Miscanthus giganteus* and wood pellets: TG-FTIR analysis and reaction kinetics. *Fuel* 82:1139-1147
25. De Jonge VN, Elliott M, Orive E (2002). Causes historical development, effects and future challenges of a common environmental problem eutrophication. *Hydrobiologia* 475 (1):1–9.

26. DeLuca, T.H., MacKenzie, M.D., and Gundale, M.J. (2006). Biochar effects on soil nutrient transformation. In: *Biochar for Environmental Management: Science and Technology*. Earthscan. pp. 251–270
27. DeLuca TH, MacKenzie MD, Gundale MJ (2010) Biochar effects on soil nutrient transformations. *Science and technology*. Earthscan, London 251–270
28. Dempster DN, Gleeson DB, Solaiman ZM, Jones DL, and Murphy DV (2010) Decreased soil microbial biomass and nitrogen mineralization with Eucalyptus biochar addition to a coarse textured soil. *Plant Soil* 354:311–324.
29. Ding Y, Liu YX, Wu WX, Shi DZ, Yang M, and Zhong ZK (2010) Evaluation of biochar effects on nitrogen retention and leaching in multi-layered soil columns. *Water Air Soil Pollution* 213:47–55.
30. Ding Y, Liu Y, Liu S, Li Z., Tan, Wang X, Zeng G, Zhou L., and Zheng B (2016) Biochar to improve soil fertility. *A review of Agronomy and Sustainable Development* 36: 1-18.
31. Duku MH, Gu S, and Hagan E (2011) A Comprehensive Review of Biomass Resources and Biofuels Potential in Ghana. *Renewable and Sustainable Energy Reviews* 15: 404-415.
32. Fushimi C, Araki K, Yamaguchi Y, Tsutsumi A (2003) Effect of Heating Rate on Steam Gasification of Biomass. *Thermo gravimetric-Mass Spectrometric (TG-MS) Analysis of Gas Evolution*. *Industrial and Engineering Chemistry Research* 42:3929-3936.
33. Gai XP, Wang HY, and Zhai LM (2014) Effects of feedstock and pyrolysis temperature on biochar adsorption of ammonium and nitrate. *Journal pone* 9(12):137.
34. Gaskin JW, Steiner C, Harris K, Das KC, and Bibens B (2008) Effect of low-temperature pyrolysis conditions on biochar for agricultural use. *Transformation Asabe* 51(6): 2061–2069.
35. Glaser B, Haumaier L, Guggenberger G and Zech W (2001) The 'Terra Preta' phenomenon. A model for sustainable agriculture in the humid tropics. *Naturwissenschaften* 88: 37-41.
36. Glaser B, Lehmann J and 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.
37. Glaser B, Birk JJ (2012) State of the scientific knowledge on properties and genesis of Anthropogenic Dark Earths in Central Amazonia (terra preta de Índio). *Geochim Cosmochim Acta* 82:39–51. doi: 10.1016/j.gca.2010.11.029
38. Glaser B, Haumaier G, Guggenberger, and Zech W (2002) The “Terra Preta” phenomenon. A model for sustainable agriculture in the humid tropics. *Naturwissenschaften* 88(1): 37–41.

39. Guire MJ, Xueying B, Nicole K, Askenaizer D, Qin G (2010) Prevention of nitrification using chlorite ion: Results of a demonstration project in Glendale, California. *Journal of American Water Works Association* 101:10- 47.
40. Gundale MJ, Deluca TH, and Nordin A (2011) Bryophytes attenuate anthropogenic nitrogen inputs in boreal forests. *Global Change Biology* (17):2743–2753.
41. Hammes K, Schmidt MWI, Lehmann J and Joseph S (2009) Changes of biochar in soil. *Biochar Environmental. Management Science. Technology. Earthscan, United Kingdom, London* (1): 169
42. Herath HMSK, Camps-Arbestain M, Hedley M (2013) Effect of biochar on soil physical properties in two contrasting soils: an Alfisol and an Andisol. *Geoderma* (209–210):188–197
43. Kirehman ML, Schmidt MWI, Lehmann J, and Joseph S (2002) Changes of biochar in soil. *Biochar Environmental. Management Science. Technology. Earthscan, United Kingdom, London* (1): 169
44. Joseph SD, Camps-Arbestain M, Lin Y, Munroe P, Chia CH, Hook J, Van Zwieten L, Kimber S, Cowie A, Singh BP (2010) An investigation into the reactions of biochar in soil. *Australia Journal Soil Respiration* 48:501–515.
45. Kirehman PN, Lehmann J, and Joseph S (2012) Indicators and a monitoring framework for the sustainable development goals: launching a data revolution for the SDGs. *Sustainable Development Solutions Network (SDSN), Paris and New York.*
46. Kluepfel L, Keiluweit M, Kleber M, and Sander M (2014) Redox Properties of Plant Biomass-Derived Black Carbon (Biochar), *Environmental Science and Technology* 48: 5601–5611.
47. Kjeldahl J. (1883) A New Method for the Determination of Nitrogen in Organic Matter. *Zeitschrift für Analytische Chemie*, 22,366-382.
48. Kookana RS, Sarmah AK, Van Zwieten L, Krull E, and Singh B (2010) Biochar application to soil: agronomic and environmental benefits and unintended consequences. *Advances in Agronomy* 112:103-143.
49. Krull ES, Lehmann J, Skjemstad J, and Baldock J (2008) The global extent of black C in soils. *Grassland ecology, management and restoration. Science publisher. Ink, New York* 13-17.
50. Krull ES, Baldock JA, Skemstad JO, and Smernik RJ (2009) Characteristics of biochar. *Organic-chemical properties. Biochar for environmental management science and technology. Earthscan* (24): 53-65.
51. Liang L, Mao Z, Li Y, Wan C, Wang T, Zhang L (2006) Liquefaction of crop residues for polyol production. *Bioresource* 1:248–256.

52. Laird DA, Brown RC, Amonette JE, and Lehmann J (2009). Review of the pyrolysis platform for coproducing bio-oil and biochar. *Biofuels Bioproduction. Biorefining* 3(5): 547–562.
53. Laird DA, Fleming PD, Davis DD, Wang B, Horton R, Karlen DL (2010) Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. *Geoderma* doi 10:1016/Laird D, Fleming P, Wang B., Horton R, and Karlen D (2010) Biochar impact on nutrient leaching from a Midwestern agricultural soil. *Geoderma* 158:436–442.
54. Lehmann J (2007) Bio-energy in the black. *Front Ecology Environment* 5(7):381–387.
55. 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
56. Lehmann J, Silva Jr, Steiner C, Nehls T, Zech W, and Glaser B (2002) 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.
57. Lehmann J, Joseph S (2011) Biochar effects on soil biota – A review. *Soil Biological Biochemistry* 43:1812–1836.
58. Lehmann J, and Rondon M (2006) Biochar Soil Management on Highly Weathered Soils in the Humid Tropics. In Uphoff, N., Edition. *Biological Approaches to Sustainable Soil Systems*, CRC Press, Boca Raton 517-530.
59. Luo X, Chen L, and Zheng H (2016) Biochar addition reduced net N mineralization of a coastal wetland soil in the Yellow River Delta, China. *Geoderma* 282:120–128.
60. McLaren D, Moyo B and Jeffery J (2012) Nitrogen mineralization: challenges of a changing paradigm. *Ecology* 85(3):591–602. McLaren D (2012) Black carbon in density fractions of anthropogenic soils of the Brazilian Amazon region. *Organic Geochemistry* 31:669–678.
61. Major J, Rondon M, Molina D, Riha S, and Lehmann J (2005) Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant and Soil* 333:117–128.
62. Mao JD, Johnson RL, Lehmann J, Olk DC, Neves EG, Thompson ML, Schmidt-Rohr K (2012) Abundant and Stable Char Residues in Soils. Implications for Soil Fertility and Carbon Sequestration. *Environmental Science and Technology* 46:9571–9576.
63. Matsubara YI, Hasegawa N, Fukui H (2002) Incidence of Fusarium root rot in asparagus seedlings infected with arbuscular mycorrhizal fungus as affected by several soil amendments. *Journal of Japanese Society for Horticultural Science* 71:370–374.
64. Meyer RK, Krueger DD (2011) *A minitab guide to statistics*. Englewood Cliff. Prentice-Hall Publishing Inc 65:230-238.

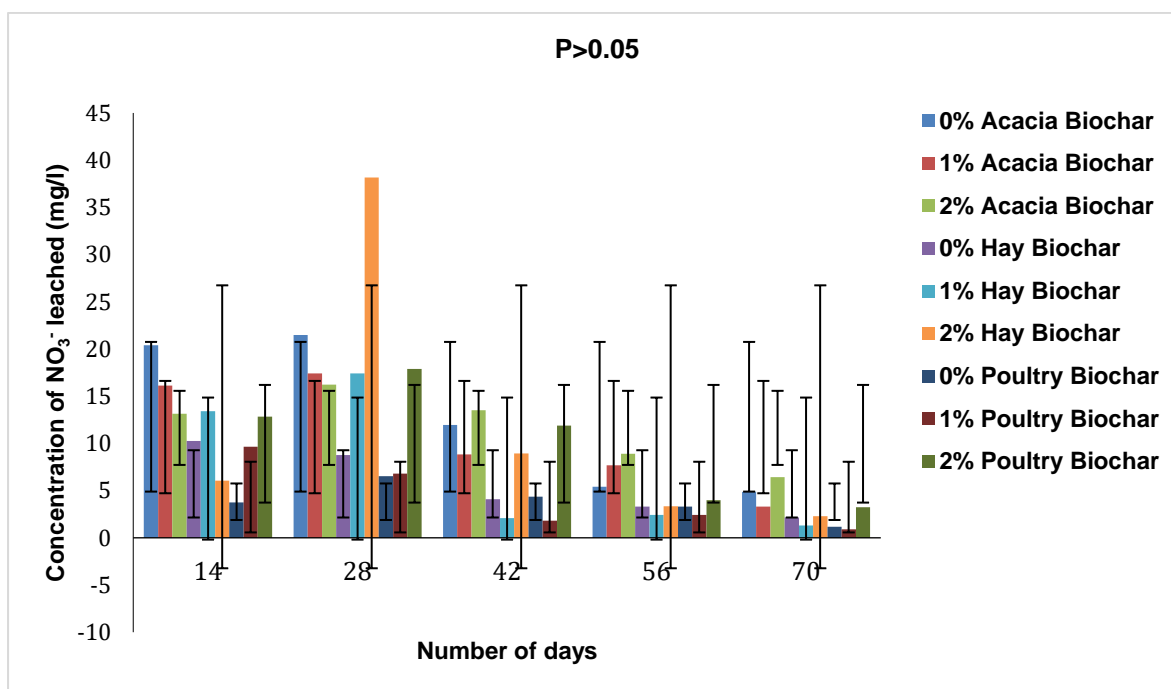
65. Mulvaney RL (1996) Total Nitrogen, Nitrogen-Inorganic Forms. In D. L. Sparks (Edition), Methods of Soil Analysis. Part 3. Chemical Methods 1123-1184,
66. Nelissen H, Rymen B, Jikumaru Y, Demuyneck K., Van Lijsebettens M, Kamiya Y, Inze D, and Beemster GT (2012) A local maximum in gibberellin levels regulates maize leaf growth by spatial control of cell division. Curriculum Biology 22: 1183–1187.
67. Nitrification Network (2014) Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with bio-char additions. Biology, Fertilizer and Soils 43: 699-708
68. 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(2):105-112.
69. Novotny EH, Hayes MHB, Madari BE, Bonagamba TJ, deAzevedo ER, de Souza AA, Song GX, Nogueira CM, Mangrich AS (2009) Lessons from the Terra Preta de Indios of the Amazon region for the utilization of charcoal for soil amendment. Journal of Brazil Chemical Society 20:1003–1010.
70. Oh K, Yamada K, Asami T, and Yoshizawa Y (2012) Synthesis of novel brassinosteroid biosynthesis inhibitors based on the ketoconazole scaffold. Bioorganic and Medicinal Chemistry Letters 22(4): 1625–1628.
71. Oh K and Chiu TKF (2009) 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.
72. Oh K (2004) Black Carbon increases cation exchange capacity in soils. Soil Science Society Am J 70:1719-1730.
73. Peake LR, Reid BJ, Tang X (2014) Quantifying the influence of biochar on the physical and hydrological properties of dissimilar soils. Geoderma 235:182–190.
74. Pereira EIP, Suddick EC, and Mansour I (2015) Biochar alters nitrogen transformations but has minimal effects on nitrous oxide emissions in an organically managed lettuce mesocosm. Biology and Fertility of Soils 51(5):573–582.
75. Prommer J, Walker TW, Wanek W (2014) Increased microbial growth, biomass, and turnover drive soil organic carbon accumulation at higher plant diversity. Global Change Biology 26:669–681
76. Raave HI, Keres K, Kauer M, Noges J, Rebane M, Tampere, and Loit E (2014) The impact of activated carbon on  $\text{NO}_3^-$ ,  $\text{NH}_4^+$ , P and K leaching in relation to fertilizer use. Eutrophication Journal Soil Science. 65(1): 120–127.
77. Randall GW, and Mulla DJ (2001) Nitrate Nitrogen in Surface Waters as Influenced by Climatic Conditions and Agricultural Practices. Journal of Environmental Quality 30: 337-344.

78. Rhoades JD, and Madison (1996) Salinity, electrical conductivity, and total dissolved solids. In D.L. Sparks (ed.) *Methods of Soil Analysis*. The Soil Science Society of America 3(5):417-435.
79. Robertson FA, Thorburn PJ (2007) Decomposition of sugarcane harvest residue in different climatic zones. *Australian Journal of Soil Research* 45: 1–11.
80. Rogovska N, Laird D, Cruse RM, Trabue S, Heaton BE (2012) Germination tests for assessing biochar quality. *Journal of Environmental Quality* 41 (4):1014–1022.
81. Rogvaska NP, Blacker AM, and Tylka GL (2016) Soybean yield and soybean cyst nematode densities related to soil pH, soil carbonate concentrations, and alkalinity stress index. *Agronomy Journal* 101(5):1019-1026.
82. Schmidt MW, and Noack AG (2009) Black carbon in soils and sediments: Analysis, distribution, implications, and current challenges. *Globalisation. Biogeochemist. Cycles* 14: 777–793.
83. Singh B, Singh B P, and Cowie AL (2010) Characterisation and evaluation of biochars for their applications a soil amendment, *Australian Journal of Soil Research impact factor* 48:516–525.
84. Sika MP, and Hardie AG (2014) Effect of pine wood biochar on ammonium nitrate leaching and availability in a South African sandy soil. *Biochar reduces N leaching and availability. Soil Science* 65(1): 113–119.
85. Sivakumaran S, Dunplos S, Cailleb S, Deurema M, and Clothiera B (2010) Charcoal biochar as carbon sequestration approach and its effect on soil's functions. *Proceedings of 19<sup>th</sup> world congress of science soil solution to change the world* 22-25.
86. Smernik RJ, Baldock J A (2005) Does Solid-state <sup>15</sup>N NMR Spectroscopy Detect all Soil Organic Stellenbosch University. *Biogeochemistry* 75:507–528.
87. Smider B, Singh B (2014). Agronomic performance of high ash biochar in two contrasting soils. *Agriculture, Ecosystems and Environment* 99-107.
88. Steiner C, Glaser B, Teixeira WG, Lehmann J, Blum WEH and Zech W (2008) Nitrogen retention and plant uptake on a highly weathered central Amazonian Ferralsol amended with compost and charcoal. *Journal of Plant Nutrition & Soil Science* 171: 893–899
89. Steiner C, Teixeira WG, Lehmann J, and Zech W (2007) Microbial Response to Charcoal Amendments of Highly Weathered Soils and Amazonian Dark Earths in Central Amazonia – Preliminary Results, in Glaser, B., Woods, W. I. *Amazonian Dark Earths: Explorations in Space and Time*. Springer Verlag, Heidelberg 104:195–21.
90. Sohi SP, Krull E, Lopez-Capel E, Bol R (2010) A review of biochar and its use and function in soil. *Advance Agronomy* 105:47–82.
91. Taghizadeh S and Tossi KL (2012) Solid waste characterization and management within university campuses case study. *University of Tabriz. Elixir Pollution* 43: 6650-6654

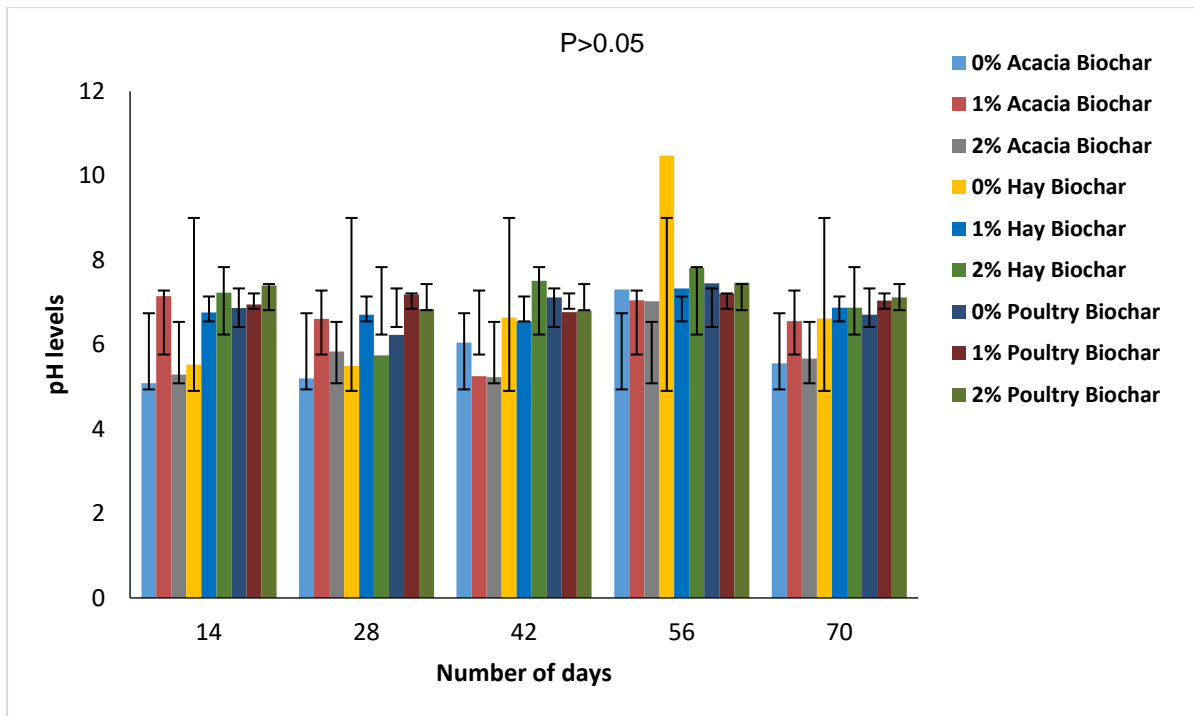
92. Tibor T, Katalin T, Emma L, Hopkins DW (2007) Promoting microbial immobilization of soil nitrogen during restoration of abandoned agricultural fields by organic additions. *Biology and Fertility of Soils*. 43 (6): 823–828
93. Thomas GW (1996) Soil pH and soil acidity. In D.L. Sparks (ed.) *Methods of Soil Analysis*. The Soil Science Society of America 3(5) 475-490.
94. Uras U, Carrier M, Hardie AG, Knoetze JH (2012) Physico-chemical characterization of biochars from vacuum pyrolysis of South African agricultural wastes for application as soil amendments. *Journal Analysis Application Pyrolysis* 98:207–213.
95. 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: 205-212.
96. Van Zwieten AL, Kimber S, Morris S, and Clemens S (2010) Influence of biochars on flux of N<sub>2</sub>O and CO<sub>2</sub> from Ferrosol. The forms of alkalis in the biochar produced from crop residues at different temperatures. *Bioresource Technology* 102(3): 3488-3497.60.
97. Wang Z, Zong H, Zheng H, Liu G, Chen L, Xing B (2015) Reduced nitrification and abundance of ammonia-oxidizing bacteria in acidic soil amended with biochar. *Chemosphere* 138:576–583.
98. Wang Z, Zheng H, Luo Y, Deng X, Herbert S, Xing B (2009) Characterization and influence of biochars on nitrous oxide emission from agricultural soil. *Environmental Pollution* 174:289–296.
99. White R E (2005) *Principles and Practice of Soil Science: The Soil as a Natural Resource*. Blackwell Publishing. ISBN 0-632-06455-2:384-392.
100. Whitman, and Lehmann J. (2009a) Pyrogenic organic matter effects on soil bacterial community composition. *Soil Biology and Biochemistry* 138: 13- 16.
101. Wu W, Yang M, Feng Q, McGrouther K., Wang H, Lu H, and Chen Y (2012). Chemical characterization of rice straw-derived biochar for soil amendment. *Biomass and Bioenergy* 47:268-276.
102. Xu Y. and Chen B (2013) Investigation of thermodynamic parameters in the pyrolysis conversion of biomass and manure to biochars using thermo gravimetric analysis. *Bioresource. Technology* 146:485–493.
103. Xu X, Thornton PE, and Post WM (2013) A global analysis of soil microbial biomass carbon, nitrogen and phosphorus in terrestrial ecosystems. *Global Ecology and Biogeography* 22 (6): 737- 749.
104. Yao LH (2004) Black pyrogenic carbon: a synthesis of current knowledge and uncertainties with special consideration of boreal regions. *Biogeosciences* 3(4):397–420.

105. Yao Y, Gao B, Zhang M, et al (2012) Effect of biochar amendment on sorption and leaching of nitrate, ammonium, and phosphate in sandy soil. *Chemosphere* 89:1467–1471.
106. Yuan J, and Xu R. (2010) The amelioration effects of low-temperature biochar generated from nine crop residues on an acidic Ultisol. *Soil Use Management* (27):110–115.
107. Zavalloni C, Alberti G, Biasiol S, Vedove GD, Fornasier F, Liu J, and Peressotti A (2011) Microbial mineralization of biochar and wheat straw mixture in soil. A short-term study. *Applied Soil Ecology* 50: 45–51.
108. Zheng J, Crowley D (2010) Effect of biochar amendment on yield and methane and nitrous oxide emissions from a rice paddy from Tai Lake Plain, China. *Agricultural Ecosystem Environment* 139:469–475.
109. Zheng H, Wang Z, Deng X, Zhao J, Luo Y, Novak J, Herbert S, Xing B (2013) Characteristics and nutrient values of biochars produced from giant reed at different temperatures. *Bioresource Technology* 130:463–471.

## APPENDIX A



**Figure 7: Effect of biochar type and rate of application on concentration of nitrate after (70) days**



**Figure 8: Effect of biochar type and rate of application on leachate pH values after (70) day**

## APPENDIX B: TURNITIN REPORT

### 2024 Khethani Thakhani final

#### ORIGINALITY REPORT

**14%**

SIMILARITY INDEX

**13%**

INTERNET SOURCES

**8%**

PUBLICATIONS

**1%**

STUDENT PAPERS

#### PRIMARY SOURCES

<b>1</b>	<a href="http://univendspace.univen.ac.za">univendspace.univen.ac.za</a> Internet Source	<b>5%</b>
<b>2</b>	<a href="http://onlinelibrary.wiley.com">onlinelibrary.wiley.com</a> Internet Source	<b>3%</b>
<b>3</b>	<a href="http://scholar.sun.ac.za">scholar.sun.ac.za</a> Internet Source	<b>3%</b>
<b>4</b>	<a href="http://googlescholar.medcraveonline.com">googlescholar.medcraveonline.com</a> Internet Source	<b>1%</b>
<b>5</b>	<a href="http://scholarworks.uark.edu">scholarworks.uark.edu</a> Internet Source	<b>1%</b>
<b>6</b>	Lusiba Sg, Odhiambo Jjo, Adeleke R, Maseko St. "The potential of biochar to enhance concentration and utilization of selected macro and micro nutrients for chickpea ( <i>Cicer arietinum</i> ) grown in three contrasting soils", <i>Rhizosphere</i> , 2021 Publication	<b>1%</b>
<b>7</b>	Simeng Li, Vanessa Barreto, Runwei Li, Gang Chen, Yuch P. Hsieh. "Nitrogen retention of biochar derived from different feedstocks at	<b>1%</b>

variable pyrolysis temperatures", *Journal of Analytical and Applied Pyrolysis*, 2018

Publication

Exclude quotes

Exclude matches  < 1%

Exclude bibliography