EFFECTS OF DIFFERENT SOURCES AND PROPORTIONS OF BIOCHAR ON SOIL CARBON SEQUESTRATION RATES AND YIELD OF MAIZE (*Zea mays* L.)

BY

ABIOLA OMOLEWA ILESANMI

B. Sc. (Hons.), M. Sc. (Ife)

A THESIS SUBMITTED TO THE INSTITUTE OF ECOLOGY AND ENVIRONMENTAL STUDIES, OBAFEMI AWOLOWO UNIVERSITY ILE – IFE, NIGERIA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY (Ph.D.) IN ECOLOGY AND ENVIRONMENTAL SCIENCE

2016

OBAFEMI AWOLOWO UNIVERSITY ILE-IFE, NIGERIA

HEZEKIAH OLUWASANMI LIBRARY

POSTGRADUATE THESIS

AUTHORIZATION TO COPY

AUTHOR: Abiola Omolewa ILESANMI (SCP11/12/H/1332)

TITLE: Effects of Different Sources and Proportions of Biochar on Soil Carbon Sequestration Rates and Yield of Maize (*Zea mays* L.).

DEGREE: Ph.D. (Ecology and environmental Science)

YEAR: 2016

I, Abiola Omolewa Ilesanmi, hereby authorize the Hezekiah Oluwasanmi Library to copy my thesis, in whole or in part, in response to request(s) from individual researcher(s) and organization(s) for the purpose of private study or research.

________________________ ________________________

Signature **Date**

CERTIFICATION

This is to certify that this research study was carried out by ABIOLA OMOLEWA ILESANMI as part of the requirements for the award of Doctor of Philosophy (Ph.D.) degree in Ecology and Environmental Science of the Obafemi Awolowo University, Ile–Ife, Nigeria.

Dr. M. B. Adewole **Supervisor**	____________________ **Signature**	________________ **Date**
Prof. A. O. Isichei **Co-Supervisor**	____________________ **Signature**	________________ **Date**
Prof. O. O. Awotoye **Director,** **Institute of Ecology and Environmental Studies**	____________________ **Signature**	________________ **Date**

DEDICATION

To God Almighty who brought me thus far

ACKNOWLEDGEMENTS

I am very grateful to God Almighty who has brought me from a very long way; for without Him, I would be nothing. My sincere appreciation goes to my supervisor cum father, Dr. M. B. Adewole, my relationship with whom surpassed that of a mere supervisor as he always wanted my progress in every area of life. I would also like to appreciate my Co-Supervisor, Prof. A. O. Isichei for his highly intelligent contributions to the success of this work. I am very grateful to the Director of the Institute of Ecology and Environmental studies, Prof. O. O. Awotoye and all the academic and non-academic members of staff of the Institute for every assistance rendered at every stage of the programme.

Special thanks to Mr. A. J. Oguntoye and the staff of the Department of Crop Production and Protection, Teaching and Research Farm, Obafemi Awolowo University, Ile-Ife for their assistance during the field work; and to Mr. S. A. Omosuli of Soil Fertility Laboratory, Department of Agronomy, University of Ibadan, Ibadan who accommodated me during the analysis of the soil and plant samples.

Words are not enough to express my gratitude to my parents; I thank God for having such wonderful parents who have contributed in no small way to my academic achievement. ‘E oo jeun omo l’oruko Jesu’. The lord will lengthen your days in good health to reap the fruit of your labour. To my dearest siblings, the B. Lawals (Bukky, Bimbo and Busola Lawal), I say thank you. And to my 8-year old best friend, Eniolakiite Sharon Ilesanmi, with whom I participated in the Youth Service Corps and did my Masters and Doctorate degrees together. Thank you for understanding that I had to be away from you a couple of times to do my work.

My deep appreciation goes to Sanimo Joseph who accompanied me to the field throughout the period of the experiment; Babalola Akinpelumi and Akilo Olalekan for their immense contributions during the practical aspects, the biochar production and the screenhouse experiments, such acts of love can never be forgotten. God will reward you abundantly and send help to you from above. I appreciate my colleagues, Bulu Yetunde and Olofinjana Bukola for the pieces of advice we shared, the information and materials you helped to pass across; and my working partners during the field work, Komolafe Oluwatosin and Aina Bukola. I'm grateful to Ilufoye Gideon and all my friends who never stopped asking about the progress of this work; Mayowa Omodara, Eletu Ishau Olatunde, Ilufoye Samson and Adedola Adepetu. I would also like to appreciate Kunle Ologbenla who helped me to transport my samples to the laboratory, Bamidele Christopher for giving me a space when I needed to work on my project, and to Awodire Yetunde, Adedoyin Daniel amongst others (oga's students), you people saw in me something that I probably didn't see in myself, you believed in me and I also learnt from you all.

Jesu-Loba Farrell, not yet far but still very far…thanks for being there.

To all who actually thought they were obstacles in my way, I am very grateful. They were the reason I never gave up for when I thought about them, it made more sense to forge ahead and never to quit.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

°C	Degree centigrade
cm	centimeter
et al.	*et alia*
ppmv	parts per million by volume
Ha^{-1}	per hectare
Km	Kilometer
%	Percentage
Pg	Petagrams of Carbon (10^{15} g)
Tg	Teragram (10^{12} g)
m^2	Meter square
mm	Millimeter
>	Greater than
<	Less than

ABSTRACT

This study investigated the chemical properties of the biochars produced from different plant wastes and assessed the effects of their applications as soil amendments on the growth performance, yield as well as the nutritional quality of maize. It also assessed their effects on the soil carbon and nitrogen dynamics and the rate of soil carbon sequestration. This was with a view to determining the residual effects of the treatments and identifying optimal strategy for enhancing carbon sequestration in soils.

The study was carried out in two phases; at the screenhouse of the Faculty of Agriculture and on the Teaching and Research Farm of the Obafemi Awolowo University, Ile-Ife, Nigeria. Biochars produced from cocoa pod husk (CPH), maize stovers (MAS) and maize cobs (MAC) were characterized using standard methods. Surface soil samples were collected from an exhaustively cropped land; air-dried and sieved through a 2 mm mesh. Ten kilograms of the sieved soil was filled into each plastic pot perforated at the bottom to enhance soil aeration. The screenhouse experiment consisted of six different treatments [CPH, MAS and MAC applied singly and in equal combination ($CPH_{50}MAS_{50}$, $CPH_{50}MAC_{50}$ and $MAS_{50}MAC_{50}$)]. All the treatments were applied at different rates (0, 5, 10, 15, 20, 25 tonnes/ha) and each replicated thrice in a completely randomized design to give a total of 108 pots. The biochars were thoroughly incorporated in the soil, watered and incubated for seven days. Maize seeds (ART/98/SW6) earlier purchased from Institute of Agricultural Research and Training, Ibadan, were sown at four seeds per pot and thinned to two stands at two weeks after sowing. Screenhouse experiments were conducted twice, but treatments were applied once. The field experiment was laid out in a randomized complete block design with twelve plots, each measuring 3.0 m x 2.5 m with an alley of 1.0 m between and within plots. The treatments

included MAS and MAC applied at 10 t/ha and no biochar serving as control, each with four replications. Maize was sown at three seeds per hole using 75 cm x 50 cm planting distance and thinned to two stands per hole two weeks after sowing. Field experiments were conducted in the dry and wet seasons. Data on growth parameters, grain yield and proximate compositions of the grains were determined. Pre-and post-cropping soil tests of the screenhouse and field were carried out using standard methods. Data obtained were subjected to two-way ANOVA and descriptive statistics.

The pre-cropping soil pH in 1:1 soil-water suspension was 7.94 and 5.89 for the screenhouse and field experiments respectively. The soil texture was sandy loam. Biochars' pH ranged from 10.77 to 11.98. The C/N ratios of the biochars were: 58.93, 44.35 and 42.23 for CPH, MAC and MAS respectively. At the screenhouse, the highest mean plant height of 160.2 ± 12.97 cm was obtained when soils were amended with MAS biochar at 25 t ha^{-1}. Similar results were obtained with the stem girth and number of leaves. Significantly ($F_{70, 107} = 1.88$; $p > 0.05$) highest grain yield of 4.27 t ha^{-1} for MAS at 15 t ha^{-1} was obtained in the first cultivation. The repeat experiment at the screenhouse gave comparable but lower values. In the field, MAS biochar at 10 t ha^{-1} had superior positive effect on the growth components of maize when the three treatments were compared. The highest mean yield of 1.50 t ha^{-1} (dry season) and 1.51 t ha^{-1} (wet season) obtained with MAS biochar was not significantly ($F_{4, 8} = 0.994$; $p > 0.05$) higher than 1.45 t ha^{-1} for dry season, but significantly ($F_{4, 8} = 32.87$; $p < 0.05$) higher than 1.11 t ha^{-1} for wet season. Maize grains from the control plots had the highest crude protein (9.72%) and ash contents (3.84%) in the dry season. Comparable, but lower values were obtained in the wet season. The MAS biochar had higher potential for carbon sequestration with 12.45 t C ha^{-1} yr^{-1} as about 79% of the initial organic carbon remained in the soil after the two consecutive maize cropping.

This study concluded that biochar application enhanced the yield, but not the quality of maize. The high residual organic carbon content indicated that biochars could be potential feedstocks for carbon sequestration.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

The Intergovernmental Panel on Climate Change (IPCC) reported that rising temperatures, drought, floods, desertification and weather extremes will severely affect agricultural production, especially in developing countries (IPCC, 2007a). According to the Panel, the carbon dioxide (CO_2) concentration near the ground level has risen from 280 mmol mol^{-1} in the pre-industrial times to the present 390 mmol mol^{-1}. At the present rate of emission, CO_2 concentration is projected to be in the range of 500–1000 mmol mol^{-1} by the end of this century, which will potentially increase global temperature by 1.8–5.8°C (IPCC, 2007a). Every year, the world-wide CO_2 emissions from energy needs increases, and by the year 2020, the world will produce 33.8 billion metric tons up from 29.7 billion metric tons in 2007 (US Department of Energy, USDE, 2010). With a large emission of CO_2, there is an increase in the threat to the natural environment and its inhabitants. Scientists and scholars have predicted impacts on health, agriculture and food supply, ecosystems, coastal zones, water resources, energy production and usage, land usage, deforestation, in addition to extreme or rapid changes in the climate (Environmental Protection Agency, EPA, 2010). Increased levels of greenhouse gases, particularly CO_2 have been associated with the burning of fossil fuels, deforestation, cultivation of grasslands and land use changes. According to Organization for Economic Cooperation and Development, OECD (2000), agricultural activity contributes 1% of the excess CO_2 to global emissions. The emission of greenhouse gases (GHGs), especially methane (CH_4)

and CO_2 results in loss of stored carbon (C) in soil and thus affects the process of soil C sequestration.

Soils worldwide contain around twice as much C (1500 Gt) as the atmosphere (760 Gt), and three times the amount found in vegetation (560 Gt), and hence constitute an enormous C reservoir (Batjes, 1996; Lal, 2004a). The recent attention to global warming has motivated the scientific community to search for efficient soil management and cropping systems to convert CO_2 from the air into soil organic carbon (SOC) (Lal, 2007a). Concerns about long-term shifts in climate patterns have also led scientists to measure SOC in agricultural landscapes and to develop methods to evaluate how changes in practices affect the sequestration of atmospheric C. Agricultural practices can render a soil either a sink or a source of atmospheric CO_2, with direct influence on the greenhouse effect (Lugo and Brown, 1993; Lal *et al*., 1995). Some authors have suggested that the most important factors to increase CO_2 mitigation and the SOC stock are the amount and quality of the crop residues added, whatever the climate effect on the decomposition rates and whatever the characteristics of soil mineralogy and soil type (Paustian *et al*., 1997; Sá *et al*., 2001; Six *et al*. 2002 b; Kong, *et al*., 2005; Bayer *et al*., 2006; Tristram and Six, 2007). While poor agricultural management can have serious consequences by dramatically speeding up the release of CO_2 emissions from soil, other practices can increase the soil C stock considerably, and thereby mitigate climate change (Schils *et al*., 2008).

One interesting abatement strategy is to sequester C in soil by means of charred biomass (biochar) (Lehmann *et al*., 2006; Laird, 2008). Biochar is material produced via pyrolysis of biomass feedstocks. It is a mixture of char and ash, but it is mainly (70 - 95%) C (Luostarinen *et al*., 2010). Soils throughout the world contain biochar deposited through natural events, such as forest and grassland fires (Skjemstad *et al*., 2002; Krull *et al*., 2008). Historical use of biochar dates back to at least 2000 years (O'Neill *et al*., 2009) when certain dark earths in the Amazon basin ("*terra preta do indio*") were found to contain large amounts of biochar (Sombroek *et al*., 2003, Lehman *et al*., 2006). These soils were found to be exceptionally fertile, in comparison to soils in the region that do not contain biochar (Lehmann *et al*., 2003a). According to Glaser (2007), copying the ancient technique of *terra preta de Indio* formation is a potential tool for both mitigating climate change and sustainably increasing agricultural productivity. Modern analogues of this Amazonian phenomenon, where aboriginal cultures boosted soil productivity of highly-weathered tropical soils mainly through the incorporation of biochar and nutrients into the soil, are referred to as biochar management systems (Lehmann *et al*., 2003a; Özçimen and Karaosmanog˘ lu, 2004; Glaser, 2007; Novotny *et al*., 2009).

Calculations have shown that putting biochar back into the soil can reduce CO_2 emissions by 12-84 percent of current values; a positive form of sequestration that offers the chance to turn bioenergy into a C negative industry (Lehmann, 2007a). Studies in both tropical and temperate climates have demonstrated biochar's ability to increase plant growth, reduce leaching of nutrients, increase water retention, and increase microbial activity. Various researchers have reported the positive effects of biochar on plant growth. Increases in yields with biochar application had been reported for crops such as cowpea (Yamato *et al*., 2006), soybean (Tagoe *et al*., 2008), maize (Yamato *et al*., 2006; Rodríguez *et al*., 2009), upland rice (Asai *et al*., 2009), paddy rice (Shackley *et al*., 2012; Sokchea *et al*., 2012) and water spinach (Sisomphone *et al*., 2012a; 2012b; 2012c). Lehmann (2007a) stressed that due to application of biochar, plant nutrients were retained in the soil and remained available to the plant thereby increased crop yields. Studies have also shown that the characteristics of biochar most important to plant growth can improve over time after its incorporation into soil (Cheng *et al*., 2006, 2008b; Major *et al*., 2010). The products produced from pyrolysis include bio-oil, a gaseous material referred to as syngas and a C-rich charcoal material known