

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

BY

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AND ENVIRONMENTAL SCIENCE**

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DEDICATION

To God Almighty who brought me thus far

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LIST OF ABBREVIATIONS

°C	Degree centigrade
cm	centimeter
<i>et al.</i>	<i>et alia</i>
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 greenhouse 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 greenhouse experiment consisted of six different treatments [CPH, MAS and MAC applied singly and in equal combination (CPH₅₀MAS₅₀, CPH₅₀MAC₅₀ and MAS₅₀MAC₅₀)]. 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. Greenhouse 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 $12.45 \text{ t C ha}^{-1} \text{ yr}^{-1}$ 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.

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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 (CO₂) 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, CO₂ 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 CO₂ 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 CO₂, 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 CO₂ 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 CO₂ to global emissions. The emission of greenhouse gases (GHGs), especially methane (CH₄)

and CO₂ 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 CO₂ 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 CO₂, 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 CO₂ 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 CO₂ 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 Karaosmanog̃ lu, 2004; Glaser, 2007; Novotny *et al.*, 2009).

Calculations have shown that putting biochar back into the soil can reduce CO₂ 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

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