Climate-Change Mitigation: A Case Study of Soil Biochar Influence on Morpho-Physiology of Crop Species and Genotypes

Funmilola A. Oluwafemi [1,2,*], Andargachew Gedebo[3], Amsalu Gobena[3], Meseret Tesema[3], Omodele Ibraheem[2], Olubiyi Ropo[1] and Oluwadarasimi P. Debo-Ajagunna[1]

[1] *National Space Research and Development Agency (NASRDA), Km 17 Airport Road, P.M.B. 437, Garki, Abuja, Nigeria.*
[2] *Department of Biochemistry, Federal University Oye-Ekiti, Km 3 Oye – Afao Road, P.M.B. 373, Oye-Ekiti, Ekiti State, Nigeria.*
[3] *School of Plant and Horticultural Science, College of Agriculture, Hawassa University, P.O. Box 5, Hawassa, Ethiopia.*
* *Correspondence: oluwafemifunmilola@gmail.com; Tel.: +2348065035799*

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Abstract:

Agriculture is estimated to contribute 40% to climate-change, hence the agricultural-sector has to reduce the climate-change impacts intentionally. The impact evaluation or assessment can be done through the cultivation of soil, production of crops or breeding of animals. Plants account for the majority of human food and improving their nutritional status, enhances food-security. Hence, making the soil more competent through the factors that influence soil organic carbon-sequestration and carbon dioxide emissions by partaking in climate smart agriculture is important e.g. adding biochar and microbial-biomass to the soil sequesters carbon to the soil, makes soil more competent, reduces to minimum carbon escape to atmosphere; and still makes crops have nutritional-benefits, improving food-security. Therefore, contributing to climate smart agriculture through climate-change mitigation; and the adoption of this practice and policy by the agriculture policymakers is crucial. In this case study, biochar was added to the soil to sequester carbon and the morpho-physiological effects on crop species and genotype were determined. At the end, the soil's improved efficiency had varying effects on barley, wheat, sorghum, common bean, and pea species; and *Awash melka*, *Hirna* and *Chercher* common bean genotypes; that were determined against some of their physical growth and anatomical parameters and characterization.

Keywords: Climate Smart Agriculture; Soil; Biochar; Morpho-Physiology; Crop Species; Crop Genotype.

1. Introduction

The structure of the Earth's atmosphere makes it habitable for living-things and it is the Earth's gravity that makes the Earth to retain its atmosphere. The Earth's atmosphere protects life by absorbing ultraviolet solar-radiation, warming the surface through heat-retention (greenhouse-effect), and reducing temperature extremes between day and night. Human activities directly or indirectly after a long-period of time through biogeochemical-feedback causes climate-change. This is because these activities indirectly affect how life is sustained; how our planet is threatened; and how various chemical-cycles govern and regulate Earth's climate and environment.

Climate-change has been recognized as a major challenge that needs to be addressed globally, through an integrated approach involving mitigation efforts as a way to keep green-house gas emissions under control, and through adaptation efforts as a way to minimize the impacts and effects of climate-change in communities around the world.

The United Nations General Assembly in 2015 did set a couple of global goals with the sole objective of transforming the world. These goals are referred to as the Sustainable Development Goals (SDGs) with the goal 13 as Climate Action to combat the drastic effects of climate-change [1-3]. Also, the Paris Agreement sets out a global framework to circumvent dangerous climate-change by restricting global warming to well below 2^0C and trying all efforts to restrict it to 1.5^0C. It also aims to fortify countries' ability to tackle the impacts of climate-change and support countries in their endeavor. The Paris Agreement is the first legally binding and universal global climate-change agreement, approved at the Paris climate conference (COP211) in December 2015. The EU and EU's Member States are the most of the 190 Parties to the Paris Agreement. The EU wants to combat climate-change by goal-getting policies both in EU countries and in collaboration with international partners.

Therefore, many communities are trying their best to reduce the climate-change impacts and effects as much as possible, and the agriculture sector is not an exception. Research program on climate smart agriculture and food-security conducts an outcome evaluation and explorative impact assessment by measuring, reporting, and verifying of carbon emissions using a contribution analysis methodology as evidence and to substantiate any contributions of agriculture to longer-term changes and impact of climate-change. The outcome, impact evaluation or assessment can be done through the cultivation of soil, production of crops or breeding of animals.

In this project, the determination of the factors that influence soil organic carbon sequestration and still making soil more competent is utilized. Predicting the soil organic carbon storage and carbon dioxide emissions during the cultivation of the soil and production of crops is key to climate smart agriculture and climate-change science. This is because carbon dioxide is the major greenhouse gas [4].

Biochar can be made through a controlled method called pyrolysis. It is a charcoal-like substance, made by burning all sorts of organic or biological materials from forestry and agricultural wastes (such as leaves, cotton husks, maize cob, sugarcane filter cake, coffee husk, avocado seed) known as biomass [5]. The biomass will be denied oxygen while all the volatile and moisture are allowed to go out; while the carbon remains and doesn't go into the atmosphere (carbon sequestration: as carbon dioxide is naturally captured through chemical, biological and physical processes in solid or liquid form), it rather increases crop production by making plant grow well when there is moisture. Biochar technology is promising in the mitigation of climate-change and in amending the soil, by improving its quality as well as giving energy as a byproduct and reducing waste.

Biochar is porous; there is good air circulation that is good for microorganisms, soil biology and for crops [6]. The porosity allows the cations to be attached to the anions in a process called the Cation-Exchange Capacity (CEC) of the biochar [7]. For the inorganic fertilizer produced in the factory, it is usually washed away once there is heavy rain; but for the biochar it can stick to the mineral nutrients (cation) attracting many anions to itself. As biochar improves the soil quality, it leads to an increased leaf area which allows more light to get to the plant (light interception) [8] that lead to more photosynthesis causing more carbohydrate production leading to more yield. This is having a very good vegetative growth. The biochar can remain for 100 years in the soil.

Biochar, therefore, has the potential for enhancing ecosystem CO_2 uptake, and crop productivity in regions with low fertility soil and poor agricultural production. As biochar effect also varies depending on the soil type, feedstock, the rate of application, type of crop, and genotype of crop (variety), this further work determines all these.

Common bean and pea are the legumes used in this project. They have edible seeds consumed worldwide. Barley, wheat and sorghum are also used in this project; they are staple cereals in many parts of the world.

1.1 Goals

- The effects of biochar on soil physical properties and on the growth of barley, wheat, sorghum, common bean and pea (immediate goal).
- Contribution towards carbon sequestration by turning the carbon in the biochar into the soil – mitigating climate-change and contributing towards increased crop production.

1.2 Objectives (3 Activities)

Activity 1: Effect of biochar on the growth parameters of three common bean genotypes (*Hirna*, *Awash melka*, *Chercher*).

Activity 2: Evaluation of the effect of biochar application on growth performance of different crop species (5 species of crops (cereals and legumes) - Barely, Wheat, Sorghum, Common bean (*Chercher*) and Pea.

Activity 3: Study the role of biochar on nodule production of common beans *Hirna*.

2. Materials and Methods

2.1 Soil collection, soil sampling and biochar production/application

The agricultural field of College of Agriculture, Hawassa University, Hawassa, Ethiopia was cleared off weeds by manually weeding with cutlass. Top soil (loamy) (0–15 cm) layer was collected from 3 locations mixed homogeneously.

Biochar was produced by pyrolysis of all sorts of forestry and agricultural wastes feedstock. The charcoal product was cooled, grinded and packaged in plastic bags until ready for use.

The biochar was mixed thoroughly to obtain a fine granular consistency that was mixed uniformly with the soil. 5% of biochar (98g) was added to the soil (95%; 1.96 kg) in two litres pots.

2.2 Experimental design

Activity 1: Had 6 treatments (common bean *Hirna* + biochar; common bean *Awash melka* + biochar; common bean *Chercher* + biochar; common bean *Hirna* + without biochar; common bean *Awash melka* + without biochar; common bean *Chercher* + without biochar). Each treatment was in a pot and replicated 3 times; with a total number of 18 pots under the shed house. Randomization arrangement was done as much as possible. The environmental condition of the shed house used for this activity is as follow: Temperature: 21.09 °C; relative humidity: 74.62 %; with 12h light and 12h darkness.

Activity 2: 10 treatments (barely + biochar; wheat + biochar; sorghum + biochar; common bean *Chercher* + biochar; pea + without biochar; barely + without biochar; wheat + without biochar; sorghum+ without biochar; common bean *Chercher* + without biochar; pea + without biochar). Each treatment was in a pot and replicated 3 times; with a total number of 30 pots under the shed house. Randomization arrangement was done as much as possible. The environmental condition of the shed house used for this activity is as follow: Temperature: 21.46 °C; relative humidity: 74.03 %; with 12h light and 12h darkness.

Activity 3: 2 treatments (common bean *Hirna* with biochar; common bean *Hirna* without biochar). Each treatment was in a pot and replicated 3 times; with a total number of 6 pots in the green house. Randomization arrangement was done as much as possible. The environmental condition of the shed house used for this activity is as follow: Temperature: 23.21 °C; relative humidity: 67.75 %; with 12h light and 12h darkness.

2.3 Data collection for samples in the three activities

- Physical examination of the soil with the biochar and biochar analysis.
- Growth analyses: Shoot parameters: plant height, leave number; Root parameter: root number [9].

- Anatomical analyses: The root anatomy was carried out at Plant Cell Laboratory, College of Agriculture, Hawassa University, Hawassa, Ethiopia through structural analysis using Scanning Electron Microscopy (SEM) of the roots and afterwards, the nodule number, nodule size and nodule weights of the samples were determined [10]. The nodule size was measured by vernier caliper.

3. Results

3.1. Physical examination of the soil

It was found that there was better soil structure and texture, as well as porosity of the biochar treated soil. This made it to retain moisture better. There was likewise good air circulation, which is good for microorganisms, soil biology and for crops (Figure 1).

Figure 1. Used top soil without biochar and with biochar

3.2. Growth analyses

The biochar had variable effects on common bean genotypes (varieties). The *Chercher* common bean genotype had more leaves than *Hirna* and *Awash melka* genotype. However, the height of the *Hirna* genotype was more than the other two genotypes (Table 1).

Table 1. Growth parameters of common beans (*Hirna*, *Awash melka* and *Chercher*) plants grown in the soil treated with biochar or soil untreated biochar.

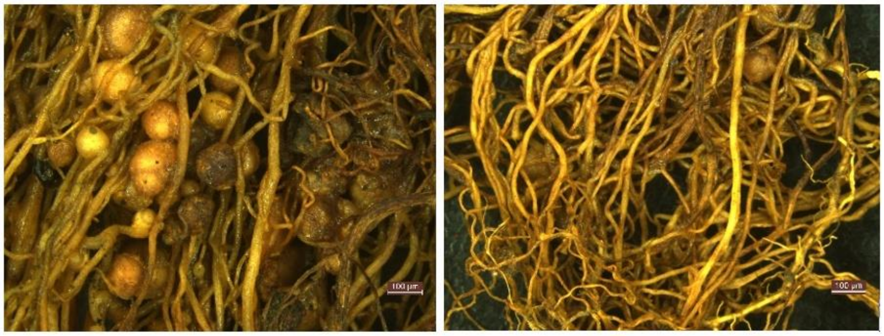
Treatments	Leaf No.	Plant height (cm)	Root No.
Hirna with biochar	7±0.00	33.00±3.68	11±1.15
Hirna without biochar	9±0.58	20.33±3.07	8±3.06
Awash melka with biochar	6±0.58	27.97±12.18	13±1.00
Awash melka without biochar	8±0.58	23.33±1.52	10±1.53
Chercher with biochar	9±1.73	22.03±4.58	8±3.21
Chercher without biochar	7±1.53	21.60±2.771	10±1.00

Biochar assisted all the crop species/types (Barely, Wheat, Sorghum, Common bean (*Chercher*) and Pea) to resist yellow colouration (yellow colouration indicates moisture/water stress). Therefore, it helped to make the moisture (water) available to the plant moderately, either if the water is excessive or too little causing drought.

The biochar added to the *Awash melka* common bean soil also aided faster germination than the counterpart without biochar.

3.3. Anatomical analyses

Using the Scanning Electron Microscopy (SEM) on the roots of the samples after harvest. There was enhanced root nodulation (nodule number, nodule size and nodule weight) of common beans *Hirna* grown in the biochar treated soil than the counterpart grown without biochar (Figure 2 and Table 2).



(a) **(b)**

Figure 2. Scanning Electron Microscopy (SEM) images of root sections showing the nodulation **(a)** common beans *Hirna* with biochar **(b)** common beans *Hirna* without biochar.

Table 2. Root nodulation of common bean *Hirna* grown with biochar and without biochar treated soil (results are means±sd of triplicate).

Sample	Nodule number	Nodules fresh weight (g)	Nodule size (mm)	Root fresh weight (g)
Hirna with biochar	158.00±66.78	0.73±0.42	2.41±0.21	5.17±3.03
Hirna without biochar	137.33±46.46	0.63 ± 0.06	2.53±0.04	4.10±1.05

4. Discussion

The *Chercher* common bean genotype grown in biochar treated soil had more leaves than the other genotypes, therefore future study on its leaves can be valuable as vegetables. Likewise, the biochar added to the *Awash melka* soil aided faster germination than the other counterpart without biochar. This means biochar reduced the likelihood of seed mortality inside the soil. For the *Hirna* common bean nodulation, as a result of very sufficient amount of carbon in the soil from the biochar, but little amount of nitrogen (nutrient); plant soil bacteria benefit from the soil carbon and lives in nodules; converting atmospheric nitrogen into a useable form of nitrogen in the soil for plant's growth. This method of supply of nutrient for plant mitigate greenhouse gases production against the use of inorganic fertilizer that produces greenhouse gases. The use of inorganic fertilizer as source of nutrient is therefore discouraged. These are in line with the work of Yeboah *et al*. [11] and Khan *et al*. [8].

The determination of the proximate content and the antioxidant properties of crops grown in biochar treated soil is important for future work. Reproducing this study with low fertility soil is recommended also.

All these are crucial because climate-change is caused primarily by carbon emissions; and the agricultural sector hence contributes a quota through climate smart agriculture predicting the soil organic carbon storage and CO_2 emissions during soil cultivation and production of crops; this is key to climate action. Biochar, therefore has the potential for enhancing ecosystem CO_2 uptake, and crop productivity.

In this project, there are improved soil physical properties, increased crops growth parameters and better nodulation with the addition of biochar to the soil before planting; this is sustainable food production through the use of biochar. These are crucial information for policy making in the plant agriculture sector.

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