

# Pryloysis of Coffee Husks for Biochar Production

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## Abstract

Effective utilization of coffee wastes has been a great challenge in Uganda despite their wider use to replenish soil organic matter. This study explored the possibility of producing biochar from coffee husks that could be used as a soil amendment for replenishing soil nutrients and also for enhancement of soil water holding capacity. Pyrolysis of coffee husks was done in a batch bio-reactor under slow pyrolysis conditions of temperatures 350°C - 550°C and residence times 30 - 60 min. For easy characterization, biochar was grinded, sieved through a 1 mm sieve and then analyzed using a computerized Thermo Graphic Analyzer with an inbuilt and integrated ELTRA 84 GmbH Precision Digital weighing scale. Proximate analysis (wet basis) of biochar gave a moisture content of 5.2%, ash content of 14.7%, volatile matter of 13.2% and fixed carbon of 66.9%. Biochar was applied to soil at different rates (0%, 5%, 10% and 20% w/w) and its effect on water holding capacity was investigated. Results show that biochar amended soils had higher water holding capacity ( $p \leq 0.05$ ) compared to biochar free soils. The water holding capacity also increased with increase in biochar amendment with a 1.5% increase in soil water holding capacity for each 1% increase in biochar application rate. Biochar was also rich in soil nutrient elements with 0.96% N, 0.39% P and 1.97% K; this increased the availability of soil nutrients for crop growth. The results suggest that biochar could be a better tool to improve soil conditions thus enhancing the sustainability of agriculture.

## Keywords

Coffee Husks, Pryloysis, Biochar, Soil Organic Matter, Soil Nutrients

## 1. Background

The effects of climate change/variability are experiences worldwide including Uganda [1]. The study on global warming shows that rapid temperature in-

creases have been noticed all over the world [2]. The global warming of the earth results from emission of greenhouse gases into the atmosphere during burning of biofuels and decomposition of organic matter. International efforts have been put in place to reduce the greenhouse gas emissions through the sequestration of Carbon in the environment [2].

Global warming can be reduced worldwide through carbon sequestration processes into the soils. Pyrolysis of biomass wastes to yield biochar is a potential method of achieving carbon sequestration [3]. The biochar is a carbon rich compound containing about 50% carbon which is applied to soils as a soil amendment and carbon sequestration is achieved. Hence biochar can be used as a tool to mitigate the current climatic change and achieve sustainable development in developing countries like Uganda.

Uganda is one of the countries in the world with the highest rates of soil nutrient depletion [4]. Furthermore, the Ugandan population is increasing at a very high rate (3.1%) compared to the world's population growth rate of 1.2% [5]. The imbalance between population growth rate and food production calls for concern about food security in the near future. The loss of soil fertility has led to the low yields in the agricultural sector which is the backbone of the Ugandan economy [6]. Soil fertility replenishment through the use of inorganic fertilizers in Uganda is too low (1.8 kg/ha) compared to (2.6 kg/ha) world average [7]. Furthermore, the inorganic fertilizers are expensive to the local farmers in terms of monetary value. They also consist of substances like methane and nitrous oxide whose emission has greatly contributed to the presence of green houses in the environment [8].

Uganda still lags behind in the use of biochar despite having the potential to generate adequate biomass feedstock for biochar production. Coffee is one of Uganda's most important commercial agricultural commodities, contributing approximately 20% to Uganda's foreign revenue [9] with an average annual production of 320,000 tons of unprocessed coffee.

The process of converting biomass to biochar leads to sequestration of about 50% of the initial Carbon content compared to the low amounts retained after biomass decomposition about 10% after 10 years [2]. Biochar hence offers a significant measure for climate change mitigation and restores the lost soil nutrients [10].

## **2. Materials and Methods**

### **2.1. Biochar Preparation**

The study was carried out at Makerere University Agricultural Research Institute Kabanyolo (MUARIK). Coffee husks were collected from Agro-max coffee processing mill located 13 km north of Kampala city. For pre-treatment purposes coffee husks were sun dried to a constant weight to reduce moisture content to below 12%. Coffee husk was fed into a batch reactor (**Figure 1**) and heated to temperatures 350°C, 450°C and 550°C for residence times 30, 45 and 60 min in a



**Figure 1.** Pyrolysis of coffee husks in a batch reactor.

slow pyrolysis anaerobic setting as recommended by [11]. The pyrolysis process was carried out in a reactor that was designed and fabricated by University of Kentucky Appropriate Technology and Sustainability (UKATS) research team. This reactor was conceived using an appropriate technology (AT) concept and built in materials that are locally available in developing countries. The reactor was used successfully in studies reported by ([12] [13] [14] [15]).

## 2.2. Chemical Properties of Biochar

The chemical properties included plant nutrient analysis (Nitrogen, Phosphorus and Potassium) and proximate analysis. The proximate analysis of the biochar was done using computerized T.G.A equipment with an inbuilt and integrated ELTRA 84 GmbH Precision Digital weighing scale (**Figure 2**). The analyzer was integrated with a non oxidizing (99.99% pure nitrogen gas) environment and an oxidizing (99.99% pure oxygen gas) environment which are computer controlled by the T.G.A software version: TGA 1.4.2.12 with an internally programmed application for analyzing biochar properties in four stages namely; Moisture content, Volatile matter, Ash content and Fixed carbon. Volatile matter was determined as per [16] standard procedures.

## 2.3. Plant Nutrient Analysis

The nutrient analysis was conducted in the Soil science laboratory at the College of Agricultural and Environmental Sciences, Makerere University. This was to quantify the nutrients that were present in coffee husks biochar in terms of Nitrogen (N), Phosphorus (P) and Potassium (K) which makes it a good soil amendment. Biochar was first converted to a plant tissue digest for easy analysis



**Figure 2.** Computerized thermal graphic analyzer equipment with a precision digital weighing scale.

using the block digester procedure [17]. About 5 g of oven dried biochar sample was mixed with 2 ml of digestive mixture in the digestion tube and heated at temperature of 110°C for about one hour. The solution was cooled and then successive drops of hydrogen peroxide were added until a colorless solution was attained. The solution was diluted with distilled water until no more sediment dissolved and a clear solution taken from the top of the test tube for analysis to determine the total Phosphorus, Potassium and Nitrogen in biochar.

### 2.3.1. Analysis of Phosphorus

The phosphorus content was determined without pH adjustment using Ascorbic acid. About 5 ml of the digest solution was mixed with 10 ml of ascorbic acid reducing agent, diluted with water, shaken well and then left to stand for about one hour to permit full color development. Using the colorimeter the sample absorbance (blue colour) at 880 nm wavelengths setting was measured and compared to the standard absorbance. The sample solution concentration and the blank solution concentration were determined from a standard graph of absorbance against concentration. The corrected concentration was obtained from subtracting the blank solution concentration value from the sample solution value. The Phosphorus content in the biochar sample was obtained in Equation (1)

$$P(\%) = \frac{c \times 0.05}{w} \quad (1)$$

where  $c$ ; is the corrected concentration and  $w$ ; is the weight of the dried sample.

### 2.3.2. Analysis of Potassium

The potassium content was determined by the Kjeldhal method followed by spectrometric analysis. About 2 ml of the digested sample solution was diluted with 50 ml of distilled water and mixed properly. The solution was sprayed into the flame of the flame photometer starting with standard, the sample and the

blank solution. The amount of potassium concentration present in the solution was read off from the calibration curve prepared by plotting absorbance readings against potassium concentrations in standard series. The concentration of potassium in the biochar sample was calculated in Equation (2).

$$K(\%) = \frac{(a-b) \times v \times f \times 100}{1000 \times w \times 1000} \quad (2)$$

where  $a$  is the concentration of potassium in the digest,  $b$  is the concentration of the blank digest,  $w$  is the weight of the sample,  $v$  is the volume of the digest solution and  $f$  is the dilution factor.

### 2.3.3. Analysis of Nitrogen

The nitrogen content was determined using the colorimetric method. The digest solution was diluted with distilled water and about 5 ml of sodium citrate was added and then the mixture allowed stand for 2 hours. Using the colorimeter the sample absorbency at 650 nm was taken. A calibration curve was plotted and the concentration of Nitrogen in the solution read off.

The Nitrogen concentration in the biochar sample expressed in %N was calculated in Equation (3).

$$N(\%) = \frac{(a-b) \times v \times 100}{1000 \times w \times al \times 1000} \quad (3)$$

where  $a$  is the concentration of Nitrogen in the solution,  $b$  is the concentration of Nitrogen in the blank,  $v$  is the total volume at the end of the analysis procedure,  $w$  is the weight of the dried sample and  $al$  is the aliquot of the solution.

## 2.4. Experimental Design

The experiment was carried out at Makerere University Agricultural Research Institute Kabanyolo (MUARIK) in plastic drained vessels. Biochar was applied to soil at different rates (0%, 5%, 10% and 20% w/w) with uniform soil mixing and all samples were packed to similar bulk densities depending primarily on the biochar application rate. Each treatment was replicated three times and each replicate included four different biochar application rates in a completely randomized design (Figure 3). All vessels were irrigated with similar volumes of



**Figure 3.** Soil samples with different treatments and their replicates (Where; 1 = Control - 0% Biochar, 2 = 5% Biochar, 3 = 10% Biochar, and 4 = 20% Biochar).

water until saturation and left in the shaded environment to prevent disruption from rain.

## 2.5. Water Holding Capacity Analysis

Soil samples were taken from each treatment at day 2 of the experiment and weighed in a pre-weighed container ( $W_1$ ). The total weight of moist sample and container ( $W_2$ ) were also taken. The samples were then dried in an oven at  $105^\circ\text{C}$  for two days until no further moisture loss occurred, reweighed and weight of oven-dried sample ( $W_3$ ) taken. The procedure was repeated for five corresponding days with varying moisture potentials and the water holding capacities of the soil were determined using Equation (4).

$$WHC = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \quad (4)$$

## 2.6. Data Analysis

The water holding capacities of soil resulting from different biochar application rates obtained from a Completely Randomized Design (CRD) experiment with three replications and four treatments were analyzed using the analysis of variance (ANOVA) to test the significance of the experiment among treatment means.

# 3. Results and Discussions

## 3.1. Effect of Pyrolysis Conditions on Biochar Yield

Temperature was one of the most important factors that affect the process of biomass pyrolysis. Biochar yield from coffee husks decreased when the pyrolysis temperature increased, with minimum yield of 29.9% recorded at  $550^\circ\text{C}$  and maximum yield of 35.09% recorded at  $350^\circ\text{C}$  (Figure 4). This was due to greater primary decomposition of the biomass samples or through the secondary decomposition of the biochar itself [18], since more volatile materials were being forced out of the char at higher temperatures reducing yield but increasing the proportion of carbon in the char as the pyrolysis temperature increased.

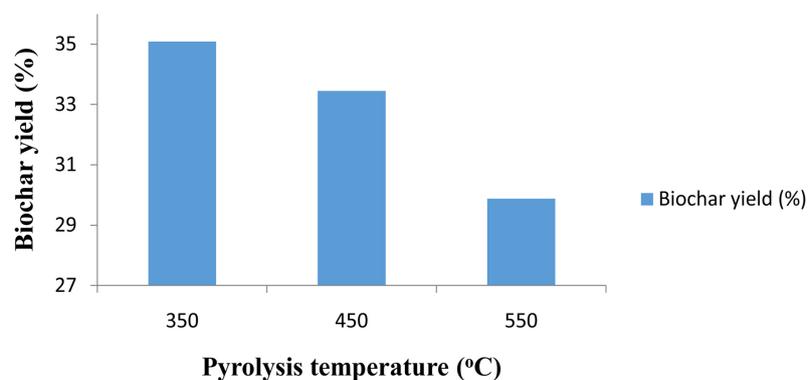


Figure 4. Variation of biochar yield with pyrolysis temperature.

A decrease in the yield of the biochar was recorded with the increase in the pyrolysis residence time, with biochar maximum yield of 36.87% recorded in 30 min and minimum yield of 34.07% recorded in 60 min at a constant temperature (Figure 5). The time of heating of biomass affects the extent and sequence of pyrolytic reactions. Since pyrolysis takes place over wide range of time, products formed earlier tend to undergo secondary reactions and allow further degradation of the already formed products [18].

## 3.2. Characterization of the Coffee Husks Biochar

### 3.2.1. Proximate Analysis of Coffee Husks Biochar

Results for different biochar samples obtained from the computerized Thermo Graphic Analyzer (T.G.A) were recorded in Table 1 using the T.G.A software version.

The proximate analysis of the coffee husks biochar results in Table 1 shows that fixed carbon content in the biochar was above 60% for the pyrolytic conditions in all the tested samples implying that coffee husks biochar is suitable for carbon sequestration [19]. This high carbon content in biochar presents a valuable climate mitigation tool as use of biochar as a soil amendment by offsetting

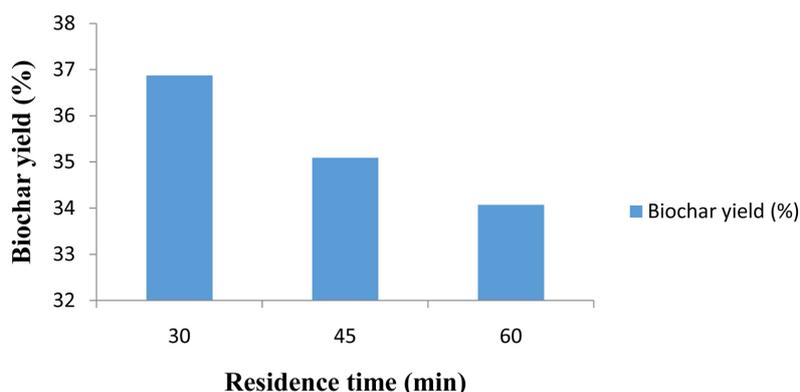


Figure 5. Variation of biochar yield with pyrolysis residence time.

Table 1. Results for proximate analysis composition of coffee husks biochar.

Biochar sample	Fixed carbon (%)	Ash content (%)	Moisture content (%)	Volatile matter (%)
A-550-60	66.87	15.23	4.62	13.17
A-550-45	65.43	14.48	4.96	14.98
A-550-30	61.71	15.01	4.64	15.08
B-450-60	64.01	14.64	5.49	19.62
B-450-45	62.12	14.07	4.77	16.84
B-450-30	63.73	12.92	5.93	17.12
C-350-60	64.41	13.16	5.86	20.43
C-350-45	63.92	13.38	6.07	18.73
C-350-30	59.23	10.23	5.98	22.52

carbon emissions into the atmosphere. The carbon present in biochar is held in an aromatic form and is resistant to decomposition when added as a soil amendment [20].

The second major component of biochar was the ash which contains important plant nutrients like Potassium, Phosphorus, Calcium and Magnesium [21]. When biochar is applied to the soil, the minerals contained in the ash alleviate deficiencies and improve crop growth. Volatile matter in the biochar was found to be low (11% to 15%) which is a good indicator that the biochar is a good soil amendment tool. High volatile matter contains a bio available carbon source that stimulates microbial activity and inhibits nitrogen availability, while low volatile matter does not appear to be readily available for microbial consumption [22].

### 3.2.2. Nutrient Analysis of Coffee Husks Biochar

The coffee husks biochar results showed presence of higher nutrient content (Table 2) in terms of (NPK) compared to the 0.92% N, 0.29% P and 0.67% K reported by [23] for maize stover biochar (Figure 6).

Also these nutrients in biochar are relatively higher compared to 0.12% N, 0.03% P, and 0.24% K present in Ugandan soils reported by [4]. Therefore biochar used as soil amendment increases the availability of nutrients for plant growth.

### 3.3. Water Holding Capacity of the Soil

Results for average water holding capacities of soil amended with different biochar application rates for soil samples taken on various days Table 3.

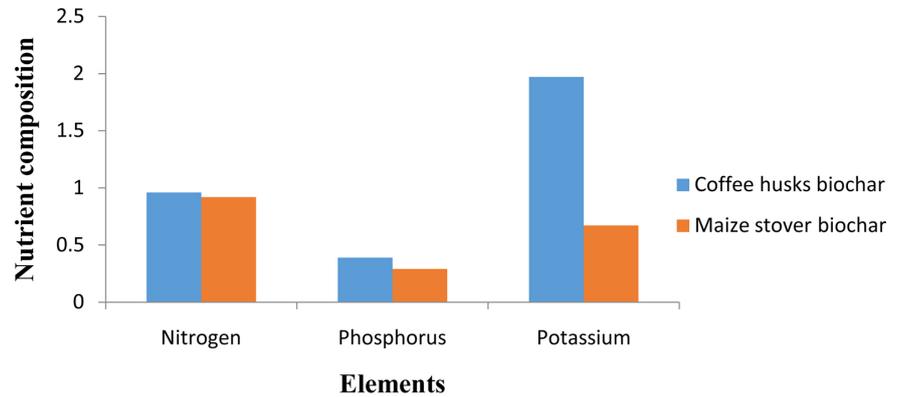
Biochar amended soils had a significantly higher water holding capacity ( $P < 0.02$ ) relative to the control while same treatments of biochar did not show any significant difference in the water holding capacity. An increase in biochar application rate increased the water holding capacity of the soil significantly at ( $P < 0.05$ ) (Figure 7). Biochar application rate from 0% - 5%, 5% - 10% and 10% -

**Table 2.** Nutrient content present in the coffee husks biochar.

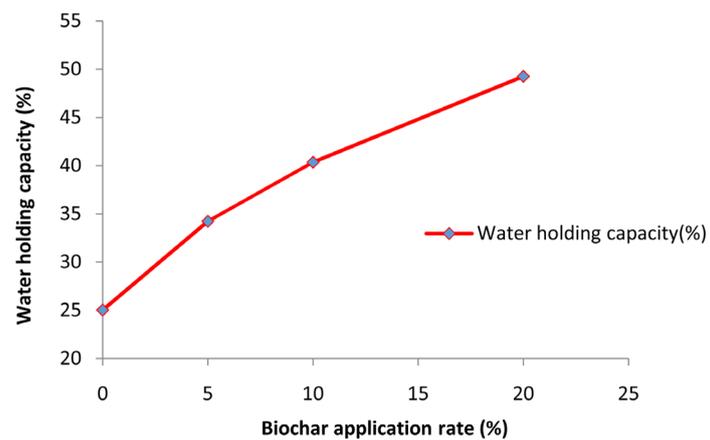
Element	Quantity (% wet basis)
Phosphorus (P)	0.39 ± 0.002
Potassium (K)	1.97 ± 0.015
Nitrogen (N)	0.96 ± 0.005

**Table 3.** Water holding capacities of the soil under different biochar application rates.

Biochar application rates	Water holding capacities of soil				
	Day 1	Day 2	Day 3	Day 4	Day 5
0%-control	31.87	28.20	22.05	22.22	20.82
5%	35.37	35.36	33.68	32.52	34.22
10%	42.97	41.02	38.67	38.43	40.75
20%	50.92	49.62	49.65	47.35	48.87



**Figure 6.** Comparison of the elemental nutrient content of coffee husks biochar and maize stover biochar.



**Figure 7.** Water holding capacity of the soil with varying biochar application rate.

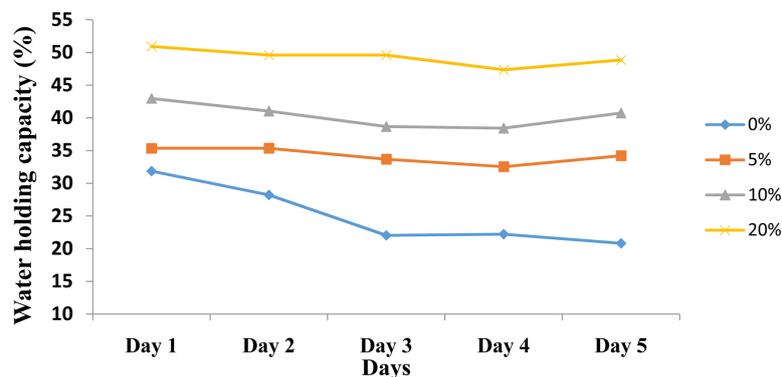
20% showed a percentage increase in the water holding capacity by 11%, 21% and 19% respectively). This is comparable to the 18% increase in the water holding capacity by addition of 45% biochar by volume to sandy soils reported by [24].

Water holding capacities of biochar amended soils were relatively constant throughout the entire period, whereas water holding capacity of the control decreased rapidly throughout the entire sampling period ( $P < 0.05$ ) (Figure 8). This was probably due to the increase in the soil bulk density, since water holding capacity decreases with bulk density and the bulk density of biochar amended soils is relatively constant with time [25].

Water scarcity is a global issue threatening the sustainability of agricultural food production [26]. The ability of biochar amendments to improve soil water-holding capacity could enhance the sustainability of commercial agriculture in arid regions which are adversely impacted by water stress conditions.

#### 4. Conclusion

In this study, the biochar derived from the coffee husks greatly depended on



**Figure 8.** Water holding capacity of different treatments sampled on varying days.

pyrolysis conditions (Temperature and Residence time) with a maximum biochar yield of 36.87 wt% attained in the reactor, and the yield of biochar decreased as the temperature and residence time of pyrolysis in the reactor increased. Biochar was characterized by both proximate analysis and nutrient analysis. Proximate analysis included a relative fraction of fixed carbon, volatile matter and ash content and nutrient elemental analysis included proportions of elemental nutrients in terms of Nitrogen, Potassium and Phosphorus. The biochar produced from coffee husks contains high percentage of fixed carbon (>60 wt%), suggesting that biochar from coffee husks is suitable for carbon sequestration and also contributes to high levels of soil organic matter. Biochar also contains nutrients with an inorganic (NPK) equivalent of (0.96:0.39:1.97) implying that coffee husks biochar is a good soil amendment. The research found that biochar used in this study increases water holding capacity of the soil by around 1.5% for each 1% added biochar. This becomes beneficial in areas of low water availability and also is another important attribute that prevents land degradation by erosion. Given the current state of knowledge, the coffee husks biochar has the potential for both greenhouse gas mitigation and as a soil amendment tool. Sustainable land management through biochar utilization may promote poverty reduction, as it results in increased soil fertility, and reduced need for fertilizer inputs which translate into more income.

### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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