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TOWARDS SUSTAINABLE BIOCHAR PRODUCTION: A LOCAL REACTOR APPROACH

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Abstract
Biochar, a porous carbonaceous substance derived from the thermochemical conversion of organic matter under oxygen-depleted conditions, exhibits physicochemical traits conducive to secure and enduring carbon sequestration in the environment. It holds substantial promise for soil enhancement (Lehmann et al., 2009). Unlike regular charcoal, biochar is expressly crafted for application in soil as part of agronomic or environmental management strategies. The incorporation of biochar into soil has recently emerged as a propitious avenue for augmenting soil quality, bolstering crop yields, and pioneering a unique approach to carbon sequestration (Lehmann et al., 2003). Possessing minimal density and high porosity, biochar functions akin to a sponge within soil, entrenching water and nutrients and averting their leaching, thereby rendering them more accessible to plants (Major, 2011). Additionally, it resists decomposition by soil microorganisms, enabling the long-term retention of carbon in the soil. The production and application of biochar in soils herald a notably auspicious potential for fostering sustainable agricultural systems and mitigating global climate change.

1.0 Introduction

Biochar is a porous carbonaceous material produced by the thermochemical conversion of organic materials in an oxygen-depleted atmosphere. It has physicochemical properties suitable for the safe and longterm storage of

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carbon in the environment and has a potential for soil improvement (Lehmann et al., 2009). Biochar differs from charcoal in that it is produced specifically for its application to soil as part of an agronomic or environmental management system. The application of biochar to soil has in recent times emerged as a promising approach to improving soil quality and crop production and a novel approach to sequester carbon (Lehmann et al., 2003). Biochar has a very low density and it is highly porous. It acts like a sponge in soil and retains water and nutrient, preventing them from leaching away, thus making them more available to plants (Major, 2011). It is also resistant to decomposition by soil microbes and can hold carbon in the soil over long periods. The production and use of biochar in soils have a very promising potential for the development of sustainable agricultural systems and global climate change mitigation.

Biochar can be made from diverse feedstock using a wide range of thermochemical conversion technologies in a process known as pyrolysis. The process results in rearrangement of the feedstock's molecules, yielding biochar and other products such as bio-oil and syngas (Taylor and Mason, 2010). Depending on the technology used, the production process can be controlled to produce more of either the biochar, oil or gas, and each of these products can have properties and uses that provide values from the process (Brownsort, 2009). Several types of pyrolysis units are available, including kilns, retorts and other specialized equipment to contain the pyrolyzed biomass while excluding oxygen. The differences between these pyrolysis units are based on several factors including heating method, particle size of the feedstock, construction material, mode of operation and heat transfer rate (Garcia-Perez et al., 2010).

The feedstock used to produce biochar can be derived from both plants and animals. They include agricultural crop residues, agricultural by-products, forestry residues, wood waste, organic portion of municipal solid waste, industrial wastewater and manures. Duku et al., (2011) has identified a significant amount of biomass resources in the country as a potential feedstock for biochar production.

The earth mound or pit is the technology used to produce charcoal in Ghana (Duku et al., 2011). This technology is however inefficient, as it releases high amounts of gases and other unburned hydrocarbons into the atmosphere and reduces the yield of the char. The efficiency rate is about 10-20% (dry basis) and leads to about 60 -70% loss in the energy input (Bailis et al., 2013).

Modern pyrolysis units are more efficient and designed to produce char under controlled conditions and capture volatiles for the production of bio-oil and syngas (Brown, 2009). A batch system reactor was therefore locally developed to efficiently and sustainably produce biochar. This study was therefore undertaken to examine the yield and cost of biochar produced from the newly designed reactor.

2.0 Methods and Materials 2.1 Study area and reactor design

The study was carried out in a locally designed reactor by ALFATRIO Ltd, located in Kumasi, Ghana from January 2012 to March 2012. The reactor consisted of a feedstock chamber with a fuel grate at the base for placing and charring the feedstock to be converted to biochar, a fuel chamber where the fuel for heating the reactor to temperatures necessary for pyrolysis to begin and a pipe to collect bio-oil during the pyrolytic process (Fig. 1). The reactor also had doors to access the feedstock and fuel.

Fig 1. Biochar reactor

2.2 Feed stocks collection and preparation

The wood shaving feedstock used for the study was collected as waste from the mills at the Wood Village in Kumasi. The firewood for heating the reactor was also collected as offcuts from the mill at the Wood Village. The offcuts were mainly from Teak (*Tectona grandis*).

The feedstock were spread on a tarpaulin in the sun to dry and packed in sacks before weighing with weighing scale. The reactor was preheated before the feedstock was introduced. The firewood for heating the reactor was weighed and fed into the fuel chamber and then ignited. The doors of the reactor were opened to facilitate the burning of the firewood to ashes to release energy for heating the reactor. A thermocouple was used periodically to determine when the desired temperature for pyrolysis was reached. The fuel wood door was then closed and the feedstock fed onto the fuel grate in the feedstock chamber for the charring process once the firewood had burnt out and the desired temperature attained.

The charring was monitored periodically and once completed; it was removed from the reactor and quenched with water to prevent it from combusting. It was then spread on the tarpaulin and allowed to dry in the sun. The biochar was then packed in sacks, weighed and ready to be used for agricultural purposes.

2.3 Statistical analysis

Microsoft excel 2007 was used to analyze the biochar yield and production cost.

3.0 Results and Discussion 3.1 Biochar production process and yield

A total of 1,460 kg of wood shaving feedstock was used to produce biochar yield of 540 kg (Table 1). An average feedstock of 122 kg was used which yielded an average charring ratio of 37%. The biochar was produced in 12 batches in 35 days with 988 kg of firewood. The yield of biochar obtained in the study is consistent with a report on woody biomass under slow pyrolysis (Honsbein, 2005). Biochar yield is dependent among other things on the nature of the feedstock used (woody or herbaceous), operating conditions and the environment of the pyrolysis units (low vs. high temperature, residence time; slow vs. fast pyrolysis, heating rate and feedstock preparation) (Laird et al., 2011). Woody biomass with high lignin contents like the one used for this study typically produces greater char yields. Similarly, slow pyrolysis rate with low temperatures leads to higher char yield (Bridgewater, 2007).

Drying the feedstock before charring also improves the pyrolysis process efficiency (Cummer and Brown, 2002) as fairly large energy input would be required for drying during the pyrolysis process. High moisture content also leads to reduction in biochar yield (Minkova, 2001).

The difference in the quantity of firewood used, maybe due to the nature of the wood used and the rains that were experienced in the course of some of the charring process. Teak (*Tectona grandis*) was found to be most effective in generating heat for the combustion process. Whenever it rained, the reactor cooled down and the fire chamber had to be heated to continue the combustion process. The differences in the days to charring may be due to heat lost from the reactor through radiation from the surfaces, air holes in the openings of the reactor and the rains. The reactor was mounted in the open and was also not insulated since it was still under construction.

Table 1 Biochar production process and yield

Batches number	Feedstock input (kg) A	Biochar yield (kg) B	Charring ratio (including moisture) % B/A	Days to carbonizing	Firewood used (kg)
1	120	53	44.2	3	80
2	122	31	25.4	2	80
3	120	54	45.0	2	80
4	120	60	50.0	1	80
5	122	41	33.6	3	80
6	120	52	43.3	4	94
7	128	33	25.8	4	86
8	122	33	27.0	4	84
9	120	47	39.2	2	74
10	124	46	37.1	3	80
11	120	50	41.7	4	90
12	122	40	32.8	3	80
Average	**122**	**45**	**37.1**	**3**	**82**
Total	**1460**	**540**	**445.1**	**35**	**988**

3.2 Cost of biochar production

The total cost for producing the 540 kg of biochar was GH¢ 1214.42 (USD 631.49). A total of GH¢ 59.84 (USD 115.08), GH¢ 247.00 (USD 475.00) and GH¢ 318.24 (USD 612.00) were spent on feedstock, firewood and transportation respectively with corresponding averages of GH¢ 4.99 (USD 2.59), GH¢ 20.58 (USD 10.70) and GH¢ 26.52 (USD 13.79) (Table 2). A total of GH¢ 239.34 (USD 124.46) with an average cost of GH¢ 19.95 (USD 10.37) per day was also spent on labour. This supports the findings of Filiberto and Gaunt (2013) that the cost of biochar is directly related to the cost of the feedstock, collection and transportation and the processing method of the feedstock used. The market value for biochar is still speculative due to lack of an established market. In the USA, some biochar companies sell their biochar products at a median price of USD 2.860 per kg or USD 2860 per metric ton (Jirka and Tomlinson, 2014). The cost of production of the biochar [GH¢ 112.44 (USD58.47)] for 50 kg bag seem to be high compared to NPK fertilizer at a subsidized price of GH¢ 39. 00 (USD 20.28) (MoFA, 2012). However, whiles the benefits of chemical fertilizers to the soil and crops are only realized in the same growing season that of biochar is for several growing seasons.

Major et al. (2010) for example in their four year's studies on maize yield with a single application of wood-derived biochar, observed increases in yield up to the fourth year.

It is therefore recommended that the locally manufactured reactor needs to address heat loss issues as well as improve heat capture system. The reactor should also be sited near the source of feedstock to reduce transportation cost. It is also recommended that government should subsidize the price of biochar just like fertilizers once farmers patronize its application.

Table 2 Biochar production cost

Batches number	**Item GH¢**					**Total Cost GH¢**
	Feedstock GH¢5/122 kg	**Firewood GH¢ 0.25/kg**	**Transportation (Feedstock and Firewood) GH¢0.13/kg**	**Reactor use GH¢ 10/ day**	**Labour cost GH¢ 20/122 kg**	
1	4.92	20.00	26.00	30.00	19.67	100.59
2	5.00	20.00	26.26	20.00	20.00	91.26
3	4.92	20.00	26.00	20.00	19.67	90.59
4	4.92	20.00	26.00	10.00	19.67	80.59
5	5.00	20.00	26.26	30.00	20.00	101.26
6	4.92	23.50	27.82	40.00	19.67	115.91
7	5.25	21.50	27.82	40.00	20.98	115.55
8	5.00	21.00	26.78	40.00	20.00	112.78
9	4.92	18.50	25.22	20.00	19.67	88.31
10	5.08	20.00	26.52	30.00	20.33	101.93
11	4.92	22.5	27.30	40.00	19.67	114.39
12	5.00	20.00	26.26	30.00	20.00	101.26
Average	4.99	20.58	26.52	29.17	19.95	101.20
Total	59.84	247.00	318.24	350.00	239.34	1214.42

1 GH¢ = USD 0.52in 2012

4.0 Conclusion

Biochar yield of 540 kg with a charring ratio of 37% was produced from the locally manufactured reactor using 1460 kg of wood shaving feedstock. The total cost of production was GH¢ 1,214.42 (USD 631.49) and comprised the feedstock, firewood, transportation, and labour cost. The high cost of production was attributed to the firewood and transportation cost. The benefits of biochar to the soil and plant growth are for several growing seasons and can therefore make up for the high cost of production. It is therefore recommended that the locally manufactured reactor needs to address heat loss issues as well as be sited near the source of feedstock to reduce the transportation cost. Government should also subsidize the price of biochar once farmers realize its potential to enhance the productivity of crops.

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