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Biochar Systems in Ghana

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Abstract:
Biochar is a pyrolysed biomass, incorporated into soil for improvement of soil health. Biochar added to soils holds the potential of a triple-win for livelihoods, environment and the climate. In environments where a lot of biomass is generated and poses disposable challenges, biochar remains a viable alternative for solving both agronomic and environmental problems, especially in highly degraded soils. Considerable research into biochar over the years have indicated its potential to solve many environmental problems, however there is still lack of knowledge about specific aspects of biochar production and use. Also, a number of assertions related to the positive impact of biochar in agriculture have not been well explained scientifically and verified. In Ghana, research on biochar is recent and currently uncoordinated with research outputs not clearly documented and visible. There is the urgent need to review available information on biochar research outputs in Ghana and provide expert opinion on the feasibility of embedding the technology in specific farming systems. The aim of this paper is to present an in-depth review of biochar research in Ghana, as it relates to agriculture and environmental management. Challenges to the biochar technology, formulation, feedstock availability and adoption rates are discussed. There is wide array of potential feedstocks for biochar production from agricultural residues. The quantity of biochar application has pronounced effect on maize grain yield where 5 t ha^{-1} significantly yielded more maize grain than 2.5 t ha^{-1}. Soils amended with cocoa pod biochar increased maize grain yield by 56 % compared to un-amended soil. Biochar can contribute to improving crop productivity on smallholdings although its supply and value chains are not formalized and the product is unfamiliar in most farming communities. Policies that integrate biochar to sustainable intensification in agriculture is recommended.

Keywords: Biochar, Maize grain yield, Partial budget, Socio-economics, Value chain

Systèmes de Biochar au Ghana

Résumé

Le biochar est une biomasse pyrolysée incorporée dans le sol pour améliorer la santé du sol. L'ajout de biochar dans les sols offre la possibilité d'un triple bénéfice pour les moyens de subsistance, l'environnement et le climat. Dans les environnements où une grande quantité de biomasse est générée et pose des problèmes d'élimination, le biochar reste une alternative viable pour résoudre les problèmes agronomiques et environnementaux, en particulier dans les sols fortement dégradés. Des recherches considérables sur le biochar au cours des années ont indiqué son potentiel pour résoudre de nombreux problèmes environnementaux, cependant il y a toujours un manque de connaissances sur les aspects spécifiques de la production et de l'utilisation du biochar. En outre, un certain nombre d'affirmations relatives à l'impact positif du biochar en agriculture n'ont pas été bien expliquées scientifiquement et vérifiées. Au Ghana, la recherche sur le biochar est récente et actuellement non coordonnée avec des résultats de recherche non clairement documentés et visibles. Il y a un besoin urgent d'examiner les informations disponibles sur les résultats de la recherche sur le biochar au Ghana et de fournir un avis d'expert sur la faisabilité de l'intégration de la technologie dans un système agricole spécifique. L'objectif de cet article est de présenter un examen approfondi de la recherche sur le biochar au Ghana, en ce qui concerne l'agriculture et la gestion de l'environnement. Les défis de la technologie du biochar, la formulation, la disponibilité des matières premières et les taux d'adoption sont discutés. Il existe un large éventail de matières premières potentielles pour la production de biochar à partir de résidus agricoles. La quantité d'application de biochar a un effet prononcé sur le rendement en grain de maïs où 5 t ha^{-1} a donné significativement plus de grain de maïs que 2.5 t ha^{-1}. Les sols amendés avec du biochar de cabosse de cacao ont augmenté le rendement en grain de maïs de 56 % par rapport aux sols non amendés. Le biochar peut contribuer à améliorer la productivité des cultures dans les petites exploitations, bien que ses chaînes d'approvisionnement et de valeur ne soient pas formalisées et que le produit ne soit pas familier dans la plupart des communautés agricoles. Les politiques qui intègrent le biochar à l'intensification durable de l'agriculture sont recommandées.

Mots-clés: Biochar, rendement en grain du maïs, budget partiel, socio-économie, chaîne de valeur.

Introduction

Biochar, definition and global history

Biochar is a product derived from the charring of organic material under limited-oxygen or charring in oxygen-free environment. It is a form of charcoal that is stable in the soil (Dugan, 2012). Others define biochar as converted woody-waste by pyrolysis, where pyrolysis is the temperature-driven chemical decomposition of biomass fuel without combustion (Demirbas, 2004). The word *biochar* is most likely derived from '*char*-red *bio*-mass' (Sohi, 2009, personal communication). This definition excludes anything that does not fall into the category of biomass. Definitions of biochar abound in literature and the range of processes and products differ. This include partial combustion, (Woolf, 2008), charcoalification (Braadbaart and Poole, 2008), among others. Without necessarily re-discussing all the various definitions and terminologies, the general consensus is that the purpose for which the product is made differentiates the different types of biochar. Also, the properties of the final biochar product depend, greatly on the feedstock type and processes of formation (such as pyrolysis temperature, woody or non-woody feedstock, type of reactor and its operation and orientation, size of feedstock, pre and post-processing etc.). However, evidence of biochar application in agriculture is limited. Indeed, there is misapplication of definition of biochar outside research. Some few commercial entities refer to charcoal as biochar and market charcoal dust as biochar. As the materials are not standardized, the end-user is unsure of what is applied to the field. Few commercial units claim to produce biochar briquets as energy source for cooking rather than for soil amendment.

With regard to agriculture and environment, (which are the main foci of this paper), the evidence indicates that the use of charcoal to improve soil fertility started in the Amazon basin and dates as far back as about 2500 years ago, and in some parts of Brazil where it is still used (Lehmann and Joseph, 2009). Similar indigenous practices had also been reported in South America (Ecuador and Peru), West Africa (Benin and Liberia) and in savannas of South Africa (Günther, 1997). In *Terra Preta* soils large amounts of black carbon indicate a high and prolonged input of carbonized organic matter, probably due to the production of charcoal in hearths. Lehmann and Joseph (2009), in their book 'Biochar for Environmental Management', report on observations by Trimble (1851) of the effect of charcoal dust in increasing and quickening vegetation growth, and on early research addressing beneficial effects of biochar by Retan (1915), Tryon (1948), Morley (1927) and Kishimoto and Sugiura (1980, 1985) in Japan. In much the same way Nishio (1996) reports on a long tradition of using charcoal as a soil improver in Japan.

Recent interest in biochar research stems from the discovery of charcoal amended *terra preta* anthrosols from the Brazilian Amazon basin, which were thought to be responsible for maintaining high levels of soil organic matter and available nutrients in anthropogenic soils (Glaser 1999; Glaser *et. al*., 2000, 2001). In addition, the search for methods to diminish recent threats of global warming from increased carbon dioxide concentration and other atmospheric greenhouse gases (GHGs), has led scientists to consider moving from a more rapid turnover biomass to a more recalcitrant biochar (charcoal) for carbon capture and storage in the soil. However, the use of charcoal as a soil fertility enhancer has only rudimentarily been practiced in many localities for years.

Beginnings of biochar research in Ghana

Observations in Ghana had indicated that crops grow well on old refuse dumping sites and produce appreciable yields, but very high increases in yields can be observed especially at old refuse and garbage incineration sites. Such observations seem to suggest that the incineration process may confer improved productivity to the soils beyond what may be derived from direct fresh manure application. Work published by Oguntunde *et al.* (2004) gave further credence to this. Oguntunde et al. (2004) show that soils from charcoal production sites at Ejura, in the Forest-Savannah transition zone of Ghana increased soil pH, Ca, Mg and K significantly above soils from non-charcoal producing sites. Maize yield was 91 % higher at the charcoal production site than at the non-charcoal production site. Further work by Oguntunde *et al* (2008) showed that the porosity and saturated hydraulic conductivity of soils from charcoal production sites were significantly higher than from adjacent sites. Sohi (2008) reported of biochar-based soil management strategies around forest margins. At these locations charring rather than open burning was apparently practiced in the conversion of forest to agriculture. This indigenous practice indicated that the resulting biochar greatly enhanced the sustainability of crop production, thereby reducing pressure for further forest encroachment.

It is known that incineration of refuse as well as charcoal production is partially anaerobic combustion of biomass and this process may to some extent involve pyrolysis. The result would be some form of biochar, which is now known to be a soil amendment.

Despite these observations, conscious use of biochar products for the purposes of soil and environmental remediation did not begin in Ghana until the late 1990s. The initial focus was on the use of charred biomass for sewage treatment. Unpublished data from the Department of Soil Science, University of Ghana indicates early attempts made in 1996 to employ charcoal dust to treat sewerage effluent for market gardening irrigation in the city of Accra.. The success was limited, in that though sediments were removed, the microbial loading of the treated effluent was still high. Many years later, a combined biochar-bio-sand filter system was used to treat waste water with the microbial load of the resultant effluent reduced below 95% (Duah Safo *et. al.,* 2004).

In the case of biochar production and use for soil fertility amendment, preliminary works must be credited to Yeboah and his colleagues, who evaluated biochar introduced from Brazil in pot studies (Yeboah *et. al.,* 2007). This research was followed by a series of both field and greenhouse conditions (Yeboah et al., 2009). A recent study by Yeboah *et. al* (2016) suggest that the carbon equivalent of 5 tons/ha of biochar application could increase maize yield by 56 %. Many other studies have indicated no response until carbon equivalents of more than 20 tons/ha have been applied (McHenry, 2009). In effect, the findings have not always been clear cut. These inconsistences have also been found in the global biochar literature (Liang *et. al.,* 2008; Sohi *et. al.,* 2010; Sohi & Shackley, 2009)..Apparently, many factors, such as feedstock (Duku *et. al.,* 2011a), charring temperature, among others, determine the quality of the resultant biochar. This implies the need for some standardization of the biochar, an issue discussed in more detail in later sections.

Though biochar is believed to retain nutrients and make them available to plants, and hence improves nutrient use efficiency (NUE) and crop productivity (Yeboah *et. al.,* 2009), the role of biochar as soil amendment within a tropical setting must focus on the peculiarities of tropical soils (Fig.1.1). Tropical soils are highly weathered, high proportion of low activity clays and low nutrient retention capacity. Many tropical soils are acidic. The relevant research question is in what way can biochar enhance soil productivity in Ghana?

Even if it is clear that biochar could be used to amend agricultural soils, the current formulation of biochar is not particularly suitable. Many studies have indicated that at least the equivalent of 5 ton^{-1} of biochar carbon application is required to see significant crop yield improvement. This would require the applications of very large volumes of the very light and fluffy material, which can be easily blown by the wind. For small experimental plots, this could be achieved, but for field sizes of 1 ha or more there would be challenge. The biochar material will require a different type of formulation, such as pelletizing or bricketing. To date, there is hardly any data on the effectiveness of pelletized biochar on soil crop productivity in Ghana.

Apart, there are issues relating to cost of production of the biochar material. The complete value chain from feedstock collection, biochar production, formulation of end product and delivery of product to end-user continues to be under-developed.

Aims

The aim of this paper is to present an in-depth review of the state of the art of biochar research in Ghana, as it relates to agriculture and environmental management. Challenges to the biochar technology, formulation, feed stock availability and adoption rates are discussed.

Methodology

Formation of writing team

The authors involved are researchers with varying expertise including Soil Science, Crop Science, Agronomy, Forestry, Chemistry, etc. from various universities: University of Cape Coast, University of Ghana., and CSIR Research Institutions across Ghana. The authors were selected based on their research and / or publish research interest and / or publications about biochar application. The authors participated in a brainstorming meeting to discuss the modalities and share responsibilities regarding the roles each author was expected to play including first draft, editing and proof reading, etc.

Literature search and selection of relevant primary studies

We searched for Ghana specific biochar-related studies published between 2008 and 2018 to cover a decade of biochar research

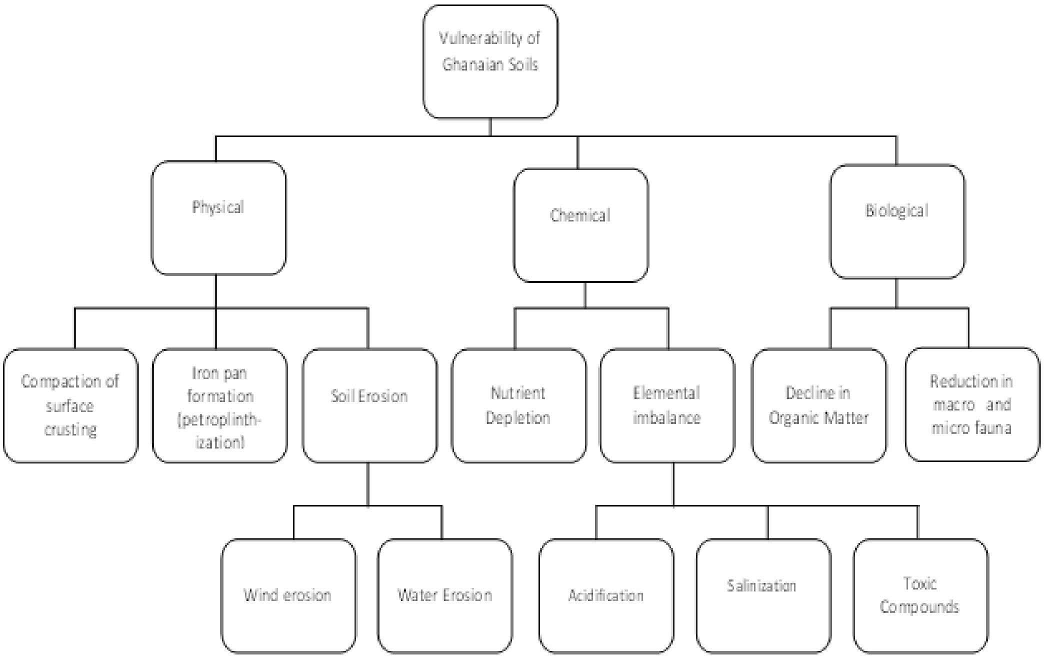

Figure 1.1: The principal types and processes of soil vulnerability in Ghana.
Source: Krogh, 1994

that reported the effects of biochar application on crop yields and soil properties., regardless of what kind of feedstock, pyrolysis condition or pyrolysis technologies used, and identified roughly 20 papers.

The search was done in Scopus, AGORA and in Google Scholar. Combinations of the following search terms were used in all databases: "Biochar" OR Charcoal OR Char * soil" OR "crop*" OR and *properties OR "growth*"AND Yield. We applied several selection criteria to ensure that minimum scientific standards were met. Studies were only included if they reported yield data on specific crop species or soil properties in a biochar amended soil with or without an organic or inorganic fertilizer source and there was a control treatment of no amendment. Biochar-related information was also collected from grey literature including annual reports, theses and communications.

Crop responses to biochar application

Nodulation and growth of legumes

The use of biochar on legume cultivation has yielded positive results.The main mechanisms by which biochar enhances legume production is through the supply of Phosphorus, and the creation of a conducive environment for rhizobia (Biederman & Stanley Harpole, 2013). Against this background, Bekwai series (Ferric Acrisol) with pH 5.6 and low rhizobia population of 20 cells/g soil was amended with Rice straw biochar and $CaCO_3$ to pH 6.48 and inoculated with rhizobia at 0, 1000, 5000, 10 000 cells/g soil to investigate the influence on nodulation and growth of soybean. The soybean was grown for six weeks in the screen house and harvested for nodule count and dry matter.

Results showed that liming only and inoculation only did not induce nodule formation, however, when liming was combined with inoculation there was nodulation (Table 1). Combining biochar with inoculation significantly ($p < 0.05$) enhanced nodulation more than combining $CaCO_3$ with inoculation(Edward *et. al.,* 2013).

Results also showed that application of biochar only increased shoot dry weight more than $CaCO_3$ only, but this difference was not significant ($p > 0.05$) (Table 2). However, combining Biochar with inoculation significantly ($p < 0.05$) enhanced shoot growth more than that of $CaCO_3$. In the case of root development, Biochar application significantly ($p < 0.05$) enhanced it at 0 and 1000 cells/g soil more than that of $CaCO_3$, however, the reverse was observed at 5000 and 10000 cells/g soil.

Growth and yield of Cereals

Common observations in Ghana had indicated that crops, including maize, grow well on old refuse dumping sites and produce appreciable yields, but very high increases in yields of maize grains can be observed especially at old refuse and garbage incineration sites. Such observations seem to suggest that the incineration process may confer improved productivity to the soils beyond what may be derived from direct fresh

Table 1: Combined effect of liming and inoculation on nodule number

Liming material	Inoculation rate (cells/g soil)			
	0	1000	5000	10,000
Control	0a	0a	0a	0a
$CaCO_3$	0a	0a	3b	1a
Biochar	0a	11c	10c	17d

Means showing same alphabets are not significantly ($p>0.05$) different

Table 2: Combined effects of liming and inoculation on shoot and root growth.

Liming material	Shoot (g/pot)				Root (g/pot)			
	0	1000	5000	10000	0	1000	5000	10000
$CaCO_3$	1.28b	1.28b	2.15b	1.18a	0.34a	0.48bc	0.52c	0.53cd
Biochar	2.34b	2.34b	2.96c	3.74d	0.5cd	0.62d	0.36a	0.42ab
CV (%)	29.9				15.5			

Source: Akom *et. al.,* 2015

manure application. Work published by Oguntunde *et al.* (2004) gave further credence to this. Oguntunde *et al.,* (2004), investigating the effect of heating and charcoal residue on maize yield in Ghana, and reported that grain and biomass yield of maize increased by 91% and 44%, respectively on charcoal site soils compared to adjacent field soils. They were able to show that soils from charcoal production sites at Ejura, in the Forest-Savannah transition zone of Ghana increased soil pH, Ca, Mg and K contents significantly above soils from non-charcoal producing sites. Further work by Oguntunde *et al* (2008) showed that the porosity and saturated hydraulic conductivity of soils from charcoal production sites were significantly higher than from adjacent sites.

In field research, conducted at Ayuom, a village near Kumasi in the Ashanti Region, Dugan (2012) reported effect of charcoal and charred maize stover on maize grain yield. His observations were that the addition of both charcoal and maize stover biochar to the soil resulted in improved cob and grain yields. According to him adding charcoal as an amendment to the plots recorded a 17.8% significant ($p = 0.002$) increase in grain yield from 4.43 t/ha to 4.93 t/ha. Similarly, the grain yield significantly ($p = 0.020$) increased to 4.71 t/ha after the amendment with charred maize stover.

Yeboah *et al.* (2009) reported that partial burning or rotational slash and char system practised in some agricultural margins of the country and who are predominantly maize farmers, typically increased crop yields.

Yield of Roots and tubers

A study by the CSIR-Crops Research Institute (Akom, *et al.,* 2015) investigated the effect of biochar and inorganic fertilizer application on yam production in a forest agro ecological zone in Ghana. The wood shavings biochar at 0, 5, 10 and 15 t/ha and three inorganic fertilizer rates were applied on a Ferric Acrisol. Vegetative growth parameters of yam were not significantly influenced by biochar and inorganic fertilizer application. However, the number of seed yams per hectare was significantly ($p = 0.05$) increased by biochar application. The study concluded that the biochar application would efficiently support yam production.

Vegetables

Konamah-Yeboah, (2015) assessed the impact of biochar application on the growth performance and yield of onion (*Allium cepa*) at the Agroforestry Research Farm of the Faculty of Renewable Natural Resources (FRNR), Kwame Nkrumah University of Science and Technology (KNUST). The results showed that soils amended with biochar significantly ($p = 0.05$) affected plant height. At 12 weeks after planting, the highest rate of biochar (39 t/ha) had the highest plant height of 18.48 cm. This was followed by the control (10.42 cm), the 26 t/ha (9.64 cm) and then the 13 t/ha (8.84 cm) biochar application. However, bulb diameter, bulb weight and dry matter yields were significantly higher for all rates of biochar amendment plots compared to the control. The highest rate of biochar (39 t/ha) recorded 163.2%, 179.4% and 205.37% increases in bulb diameter, bulb weight and dry matter yield respectively compared to the un-amended control.

Another study by Korankye (2015), at the same Faculty (FRNR), investigated the effect of different sized biochar particles on the growth and yield of cowpea. Even though the plant heights of biochar amended soils (26 t/ha) were higher, irrespective of the particle size, compared to the un-amended control soils, the differences were not statistically significant. The yield parameters also followed similar trend with the fine biochar recording the highest number of pods per plant (8), number of seeds per pod (8) and weight of seeds (19.14 g) compared to coarse biochar (8,7 and 18.24 g) and the control (6, 7 and 16.82 g) plots.

Type and Mode of biochar application and their effect on soil properties

The rate and methods of application of biochar to soils may vary. In order to achieve maximum agronomic benefits from biochar application, it is imperative to realize that the effectiveness of biochar may be influenced by the method of application (De Gryze *et al.,* 2010; Steiner *et al.,* 2008). The various ways include mixing with fertiliser and seed (a biochar/soil/seed/fertilizer mixture), surface application in no till systems, uniform soil mixing, (incorporation into soil), top-dressed, ~~hoeing into the ground~~, and spreading around farms to capture run off (Duku *et al.,* 2011). The type of application method adopted for each soil will depend on the farming system, available machinery and labour.

Low charcoal additions (0.5 t/ha) have shown marked impact on various plant species, whereas higher rates seemed to inhibit plant growth (Ogawa *et. al.,* 2006). This phenomenon provides opportunities for further inquiry. In their studies, Dugan *et al.,* (2010) observed that uniformly mixing < 0.5 mm sieved charcoal, sawdust and maize stover biochars at 5, 10 and 15 t/ha with three Ghanaian soils (sandy loam (Chromic Lixisol); Silt Loam (Ferric Acrisol) and Laomy Sand (Ferric Lexisol)) increased water holding capacities of all the soils. However, doubling and tripling the rates of application from the 5 t/ha recorded no significant difference among the rates and in some case recorded a decrease beyond 10 t/ha. The authors concluded that 5 t/ha is the optimum application rate.

Another study conducted by Goka, (2015) assessed the effect of application of different particle sizes of biochar on the height, collar stem girth, above and below ground biomass distribution of okro. The treatments consisted of four different sizes of *Gliricidia sepium* (10 mm-coarse biochar (T1), 5 mm, -granulated biochar (T2), ≤ 2 mm, - fine biochar (T3) and 0 mm - control (T4)) all applied at 5 t/ha. The different sizes of biochar were thoroughly incorporated into the soil before constructing the beds. The results showed a non-significant difference in all the parameters concluding that the application of biochar to the soil was not dependent on the particle size. In the earlier studies, Korankye (2015) reported that fine biochar recorded the highest plant height (20.30 cm) and diameter (5.88 cm) compared to coarse biochar (18.4 cm, 5.22 cm) and the control (17.8 cm, 5.33 cm) plots. The difference was however not significant for both the biochar plots and the control. The yield parameters also followed similar trend with the fine biochar recording the highest number of pods per plant (8), number of seeds per pod (8) and weight of seeds (19.14 g) compared to coarse biochar (8,7 and 18.24 g) and the control (6, 7 and 16.82 g) plots. The difference was also not significant for both the biochar plots and the control plots.

Crop yields, particularly on tropical soils, can be increased if biochar is applied in combination with inorganic or organic fertilizers (Frimpong *et al.,* 2016). Mixed application of organic matter and biochar can enhance soil water retention due to its pore structure which is able to trap nutrient-rich water within the pores, resulting in nutrient retention (Oguntunde *et al.,* 2008; Sohi *et al.,* 2010). The combined application of biochar and organic or inorganic fertilizer has the potential to increase crop productivity, thus providing additional incomes, and reducing the quantity of inorganic fertilizer use and importation (Quayle, 2010; Frimpong *et al.,* 2016). Other alternatives could involve the application of biochars with soil surface modifications such as construction of beds, combining biochars with irrigation or pre-treatment of the biochar before application to soils.

Amoakwah *et al.* (2020) found that corn cob biochar application increased humic and fulvic acids concentrations in a coastal savanna Haplic acrisol, leading to increased stratification of total organic carbon content in the soil, with the HA showing a relatively stronger effect than the FA. Among their treatments of 0. 15 and 30 t biochar ha^{-1}, respectively, the biochar application rate of 30 t ha^{-1}, showed a significantly lower E465/E665, implying the dominance of high molecular weight humic acid-like substances, and increased degree of aromaticity of the TOC. The E465/E665 ratio is an indicator of total organic carbon (TOC) humification process (Chen *et al.* 1977) and the quality of TOC in soils. The E465/E665 ratios also reflects the extent to which TOC is dominated by high molecular weight compounds. A smaller ratio suggests an increasing proportion of aromatic chain structures and a higher degree of aromatic condensation (Khan, 1959). In a similar study by Zhao *et al.* (2018), incorporation of biochars pyrolyzed at 300 and 500 °C to Earth-cumuli-Orthic Anthrosol led to a significant increase in the content of soil organic carbon and humic fractions. Amoakwah *et al.* (2020) also showed that increasing the rate of corn cob biochar increased the stratification of TOC as well as the concentrations of extracted HA and FA, with HA showing greater increases compared with FA. This is indicative that biochar application increased both aliphatic and aromatic quality (which is associated with recalcitrance) of TOC. Coupled with the lower E465/E665, the observation suggests that addition of high amounts of biochar; 30 t ha^{-1}, in this study, has potential to improve the stability of soil organic carbon and hence soil C sequestration in a tropical agro ecosystem by improving the aromatic TOC quality.

Many authors have reported positive plant yield responses following biochar application –'(Akoto-Danso *et al.,* 2019; Carter et al., 2013; Gautam *et al.,* 2017; Biederman and Harpole, 2013). Positive yield responses in biochar amended soils have been attributed partly to improved soil physical and hydraulic parameters, such as decreased soil penetration resistance and bulk density (Busscher *et al.,* 2011) and increased water-holding capacity (Kinney *et al.,* 2012). Also, the high porosity and specific surface area of biochar can improve total pore space and gas transport at the soil-atmosphere interface and within the soil ecosystem (Sun *et al.,* 2013). Amoakwah *et al.* (2017) showed that corn cob biochar application can improve soil water retention, with minimal improvements in convective and diffusive gas. Using intact soil cores taken from a field experiment with no biochar control plots and others treated with 10 t ha^{-1}, 20 t ha^{-1} without or with phosphate fertilizer, respectively, soil water retention was measured within a pF range of 1 to 6.8 while gas transport parameters (air permeability, ka, and relative gas diffusivity, Dp/D0) were measured between pF 1.5 and 3.0. The results indicated that addition of 20 t ha^{-1} of biochar increased soil water retention compared to the untreated and the 10 t ha^{-1} biochar amended soil due to increased microporosity (pores< 3 µm). The study also showed that convection percolation threshold declined by 15 to 85% while diffusion percolation threshold reduced by 34% and 18% in the 20 t ha^{-1} biochar treatments, regardless of the presence or absence of P fertilizer compared with the control. Soil structural stability, which depends on the spatial heterogeneity of the different soil components (Dexter, 1988).

In a 40 days' pot experiment done to investigate the effects of corn-cob biochar and compost applied solely or in combination at application rates of 20 tons ha^{-1}, respectively, Mensah and Frimpong (2018) observed that biochar and compost applied singly or in combination, significantly increased soil pH, total organic carbon, available phosphorus, mineral nitrogen, reduced exchangeable acidity, and increased effective cation exchange capacity in both the Rainforest and Coastal Savannah soils. Moreover, the biochar and compost applications increased the height, stem girth, and dry matter yield, of both a local and improved maize varieties, showing that biochar applied solely or in combination with compost offers the potential to enhance soil quality and improve crop yield.

Similarly, Amoakwah et al., (2017) found increased soil organic C (SOC) by 28 to 66% in the biochar amended in a highly weathered tropical sandy loam soil, amended with corn cob biochar at rates of 0, 10 and 20 t ha^{-1}, respectively, while electrical conductivity decreased relative to the unamended soil. They observed that the water-stable aggregate fraction increased by 27 to 53% in biochar treatments compared with the control. Biochar addition increased the tensile strength of smaller aggregates (1–2 mm) fraction, but decreased that of the large aggregates (4–8 and 8–16 mm), improving soil friability and workability in the 20 t ha^{-1} biochar treatments. They concluded that biochar is a potential tool to tackle the rate of degradation in highly weathered tropical soils by improving their physical quality and thus minimizing the effects of soil erosion

Toxic compounds in biochar

According to Accra municipal solid waste (MSW) fact sheet, Accra generated a total of 900, 000 metric tons of MSW in the year 2020 (CCAC, 2014) is a rapid rise from 760,000 tons in 2011 (Duku et al., 2011b). this MSW is estimated to contain at least 67% organic matter (CCAC, 2014) 4which is indicative that MSW in Ghana can be used as feedstock for biochar production. MSW in Ghana is rarely source sorted, therefore, the potential presence of heavy metals in MSW may pose a limitation to MSW use as biochar feedstock (Agblevor, 2007).

The possibility of biochar releasing toxic compounds into natural systems may emanate from the source materials used to make the biochar, the pyrolysis temperature and the final properties of the biochar especially the solution pH. This is because the solution pH and the pyrolysis temperature, may affect the speciation and the availability of these elements in natural systems (Evangelou, 1998). The major source of concern for biochar applications to soil and other natural systems lies in the possibility of biochar introducing noxious substances such as heavy metal(loid)s, Polycyclic Aromatic Hydrocarbons (PAH) and other carcinogenic and mutagenic compounds into natural systems. In this regard the application of biochar to natural systems provides both a solution and a problem. While certain heavy metals such as Zn, Mn and Cu, may be pose threat to human health, these metals are also important micronutrients needed by crops for proper functioning, therefore feedstock and biochars containing these metals may not necessarily pose a threat to the environment. It is therefore necessary to take into consider-ation the pyrolysis temperature of the biochars before their application to the soil. For example, biochars pyrolyzed under temperatures below 300°C are known to be acidic. Under these conditions, most of these elements may not be in available forms when applied to soils. The other issue worthy of nothing is that the application of high pH biochars which have the potential of raising soil pH also have the potential of precipitating these metals from solution, thereby the application of biochars from MSW may not necessarily affect soils adversely.

Some authors (Hale *et al.*, 2012; Spokas *et al.*, 2011b) have used quantitative and qualitative methods to determine potential organic pollutants in biochar produced from woody feedstock. Hale *et al*. (2012) showed that biochar may contain substantial amounts of potentially toxic compounds including polycyclic aromatic hydrocarbons, polychlorinated dibenzo-p-dioxins and dibenzofurans, polychlorinated biphenyls, and heavy metals), which can have negative effects on the soil biology and water if applied to soils without due caution. The wide array of organic chemicals or potential contaminants including volatile organic compounds (VOC), PAHs, and dioxins produced from biomass pyrolysis (Ghidotti *et al.,* 2017a; Spokas *et al.,* 2011b) found in biochar may pose a challenge to its widespread use for agriculture due to their toxicity to soil microorganisms and plants (Wang *et al.*, 2017b). This suggests that biochar application may adversely impact agri-food systems or pose ecotoxicity due to biochar's inherent contaminants. Thus, the much publicized positive effect of biochar on food security and provision of ecosystem services may suffer a major drawback. However, as far as we know, there is a dearth of studies in Ghana to confirm the toxicity of biochar, especially as most of the studies conducted in Ghana have involved crop residues and other agricultural wastes as feedstock for biochar production. We propose that, comprehensive studies should be done with the many varied feedstock available in Ghana to provide a clearer understanding of the formation, total, and bioavailable content of organic pollutants such as VOCs, PAHs, and dioxins following biochar additions to soils. These studies should focus on the possible enrichment or depletion of these heavy metals in the final biochars. Also, the availability of these elements and the factors controlling their availability in soils is very important, therefore need further study. The findings from the study will provide very important information needed for safe application of biochar in soil and also lead to the development of safety standards for biochars which are applied to soils.

Socio-economics of biochar usage

Opportunity cost of biochar and feedstocks

Biochar is currently not a common traded commodity on Ghanaian markets. The government facilitated the installation of reactors in centralized locations in some communities across the country. Farmers have to acquire their own feedstock each season for charring in these reactors. Twelve sources of feedstock mainly agricultural crop residues from maize, rice, yam, millet, sorghum, groundnuts, cowpea, shea nuts, cocoa and oil palm were identified among farm households surveyed in the coastal, forest, transition and savannah zones (Figure 2). Generally, maize residues may be the most

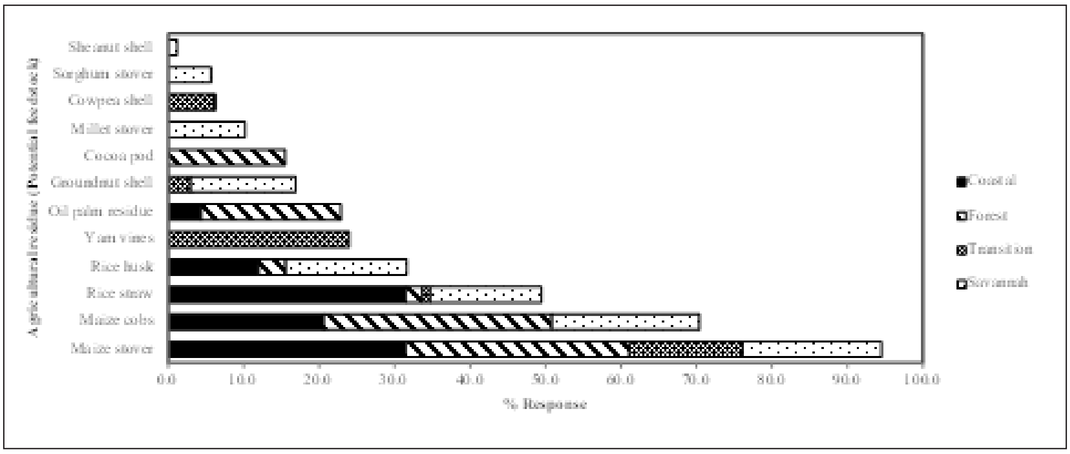

Figure 2: Distribution of farm level feedstock across agro-ecological zones
Source: Obiri *et al.,* 2012; Osei-Adu *et al*., 2015

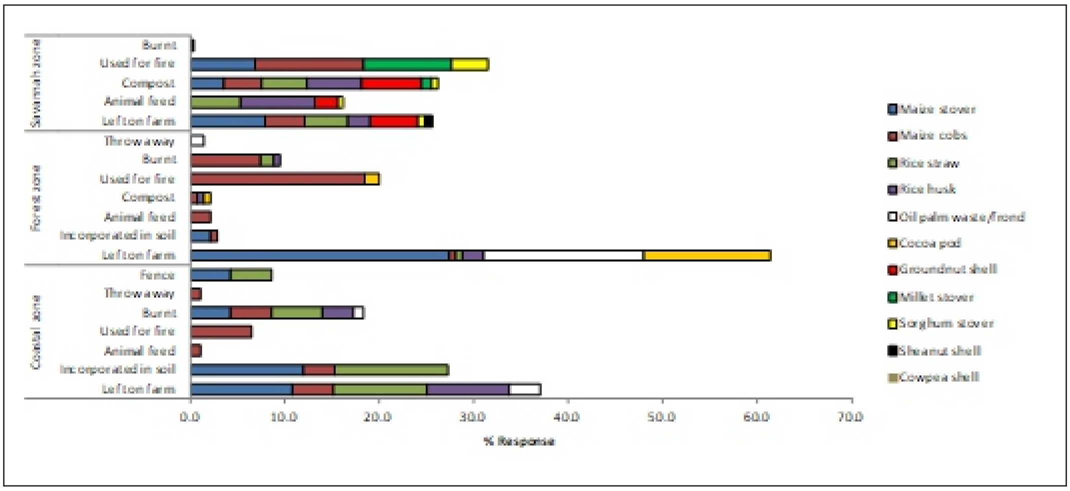

Figure 3: Uses/disposal of farm level feedstock across agro-ecological zones
Source: Obiri *et al.,* 2012

available feedstock for biochar.

In most cases farmers leave these residues on the farm or incorporate into the soil to decompose. Maize cobs, rice waste and cocoa pods may be burnt in the coastal and forest zones. Maize cob is also used for fire in these areas (Figure 3). Whereas in the coastal and forest areas agricultural residues may be more available for charring, the opportunity cost of doing so in the savannah zone will be high as farmers often (74% of cases) use maize, rice, millet and sorghum residues for fire, compost and animal feed which is critical for agricultural production and household food security. This notwithstanding, residues left on the farm, burnt and thrown away may generally be available for charring, in 52% of the cases (Figure 4). This can be obtained mainly from maize stover, rice straw, rice husk, oil palm wastes and cocoa pods

For farm production in Ghana, the opportunity cost of the use of biochar is the value of the profit from the next alternative land cultivation/soil amendment practice in its best use. This could be quantified in terms of how much the farmers would have earned from the best alternative agronomic practice in the absence of the increased production operations induced by the use of biochar or the profit forgone by switching from the current production practice of slash, burn and apply inorganic fertilizer to the new practice of substituting some proportion of the inorganic fertilizer with biochar for increased yield.

Fertilizer savings (partial budget)

Biochar has the potential to reduce fertilizer requirements in crop production. A reduction in fertilizer requirement of 7% by the application of 5 tha^{-1} biochar has been reported (De Gryze *et al.,* 2010). Gaunt and Cowie (2009) also estimated a 10% - 30% reduction of nitrogen fertilizer use with

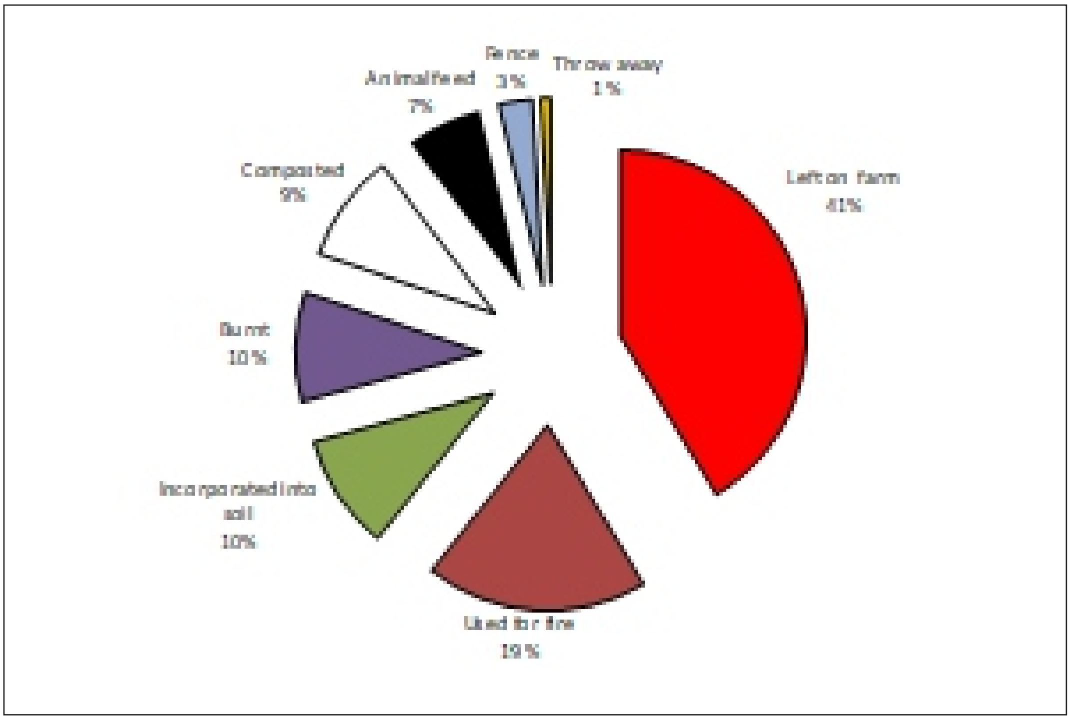

Figure 4: Disposal/uses of agricultural residues
Source: Obiri *et al.,* 2012

biochar application. New elements of cost with the use of biochar under a subsistence maize production in Ghana include cost of biochar, its haulage to the farm and application (Table1). Farmers can obtain biochar by purchasing from biochar sellers, by making it themselves, through community or group biochar making, or by share burning arrangements where the trash from the field is turned into biochar by someone other than the farmer so that the biochar is shared between the farmer and the biochar producer. Otabil (2013), reports that biochar use in smallholder crop production will not be profitable if it is purchased at the market rate of $264/ton (at the 2022 exchange rate of $1≈ GH₵7.4), unless the farmers produce the biochar themselves from a community owned reactor at little or no cost. Results from a partial budget analysis indicate that the value of the resulting yield from substituting 50% of the recommended rate of nitrogen fertilizer with 2 tons of biochar could not compensate the additional cost of biochar per a hectare of maize when biochar is purchased (Table 3 and Table 4). However, producing under a subsidized condition from a community reactor yielded surplus biochar for sale which increased the net income (Table 4).

Biochar supply chain

Figure 5 illustrates the state of the biochar supply chain in Ghana. It describes the chain of economic activities from the procurement

Table 3: Partial Budget Analysis for Maize Production with biochar at Ayuom (Forest zone): Farmer Purchases Biochar

Item	GH¢/Ha	Item	GH¢/Ha
With biochar		Without biochar	
Additional Cost (A1)		Reduced Cost(B1)	
Cost of biochar[a]	4000.00	Fertilizer	140.40
Transport of biochar	26.60	Haulage of fertilizer	2.39
Incorporation of biochar	360.00	Fertilizer application	36.00
Fertilizer[a]	70.20	Jute sacks	74.10
Labour for fertilizer application	18.00	Polyethene sheet	55.58
Haulage of fertilizer	1.20	Transport of produce	129.68
Jute sacks for maize	113.62	Burning of trash	10.00
Polyethene sheet	85.22	**Total Reduced Cost**	**448.14**
Transport of produce	198.84		
Total Additional Cost	**4873.67**		
Reduced income(A2)		Additional Income(B2)	
None[b]	0.00	Revenue from increased yield	1580.00
Column Total	**4873.67**	Column Total	**2028.14**
Change in Net income ((B1+B2) - (A1+A2)	-2845.52		

Source: Otabil, 2013

Table 4: Partial Budget Analysis for Maize Production with biochar at Nyankpala (savannah zone): Farmer Purchases Biochar

Item	GH¢/Ha	Item	GH¢/Ha
With biochar		Without biochar	
Additional Cost (A1)		Reduced Cost(B1)	
Cost of biochar[a]	4000.00	Fertilizer	140.40
Transport of biochar	26.60	Haulage of fertilizer	2.39
Incorporation of biochar	180.00	Fertilizer application	18.00
Fertilizer[a]	70.20	Jute sacks	49.40
Labour for fertilizer application	9.00	Polyethene sheet	37.05
Haulage of fertilizer	1.20	Transport of produce	86.45
Jute sacks for maize	74.10	**Total Reduced Cost**	333.69
Polyethene sheet	55.58		
Transport of produce	129.68		
Total Additional Cost	4546.34		
Reduced income(A2)		Additional Income(B2)	
None[b]	0.00	Revenue from increased yield	741.00
Column Total	4546.34	Column Total	1074.69
Change in Net income ((B1+B2) - (A1+A2)	-2845.52		

Source: Otabil, 2013

of feedstocks to the consumption of the pyrolysis product i.e., biochar. The main sources of feedstock for charring include agricultural crop residues, biomass from clearing of agricultural land, forestry residues, organic portion of municipal solid waste, industrial wastewater and manures (Duku *et al*., 2011). The bulk of feedstocks from crop residues and forestry wastes can be obtained directly from farmers' fields and wood processing industries respectively.

The pyrolysis or process of charring/ carbonizing feedstock into biochar with a reactor is being operated by farmers, district assembly/local community, research institutions and private entrepreneurs. Farmers may produce biochar using agricultural wastes from farms and apply on the farm. Feedstocks may be conveyed to the district assembly/local community reactor for processing into biochar at a fee. Private entrepreneurs also harvest feedstock from the desired sources for charring in their own reactor or biochar production centres (e.g. CSIR-Soil Research Institute) at a fee. In addition to biochar, other by-products (bio-oil and syngas) produced during pyrolysis may be harvested for sale. Some private companies produce briquette (biochar mixed with a binder) from wood wastes as source of fuel that could be sold at the supermarket,

Table 5: Partial Budget Analysis for Maize Production with Biochar from farm clearing at Ayuom – with Community Owned Biochar Reactor

Item	GH¢/Ha	Item	GH¢/Ha
With biochar		Without biochar	
Additional Cost (A1)		Reduced Cost(B1)	
Gathering of biomass	3,918.50	Fertilizer value	140.40
Loading of biomass	509.40	Haulage of fertilizer	2.40
Transportation of biomass	687.70	Fertilizer application	36.00
Offloading of biomass	101.90	Jute sacks for maize	74.00
Chopping of biomass into appropriate sizes	1,018.80	polyethene sheet	55.60
Loading of biomass into kiln	509.40	Transport of produce	129.70
Nurturing of the burning process	611.28	Burning of trash	10.00
Removal of biochar from kiln	50.90	**Total Reduced Cost**	**448.10**
Weighing and bagging	101.90		
Sacks for biochar	305.60		
Starter (Fuel wood for reactor)	101.90		
Water use	20.40		
Transport of biochar	26.60		
Incorporation of biochar	360.00		
Fertilizer	70.20		
Labour for fertilizer application	18.00		
Carriage of fertilizer	1.20		
Jute sacks	113.60		
polyethene sheet	85.20		
Transport of produce	198.80		
Total Additional Cost	**8,811.30**		
Reduced income (A2)		**Additional Income (B2)**	
None	0.00	Revenue from increased yield	1,580.00
		Sale of Surplus Biochar	16,376.00
		Total Additional income	17,956.00
	8,811.30	Column Total	18,404.00
Change in Net income ((B1+B2) - (A1+A2))		9,592.830	

Source: Otabil, 2013

restaurant/food service industry, households or exported to foreign markets. ALFATRIO Ltd. a private local reactor designer in Kumasi for example is producing biochar for supply to poultry farmers. In the future, financial service providers can provide loans to the producers for purchase of the pyrolytic equipment and supplies for biochar production. Research Institutions such as the Engineering Departments from the various Universities and Institute of Industrial Research can play an important role of improving on the efficiency of reactors to increase biochar yields.

NGO's, research and academic institutions and private entrepreneur/middlemen are involved with supplying biochar to users. NGO's such as Abokobi Society Switzerland (ASS) and Deco has for the past years been promoting the use of biochar in Northern Ghana to help improve soil fertility on farmlands. Research and academic institutions such as Soil Research Institute, Crops Research Institute, Savanna Research Institute and the Universities use biochar for on-station and on-farm trials. They are involved in disseminating research results as well as extension activities on spreading knowledge on the benefits of biochar production and application. There is a potential for private entrepreneur / middlemen to supply biochar. Retailing biochar is uncommon currently; there are reports of it being sold in the supermarket in the briquette form possibly for grilling. Biochar and

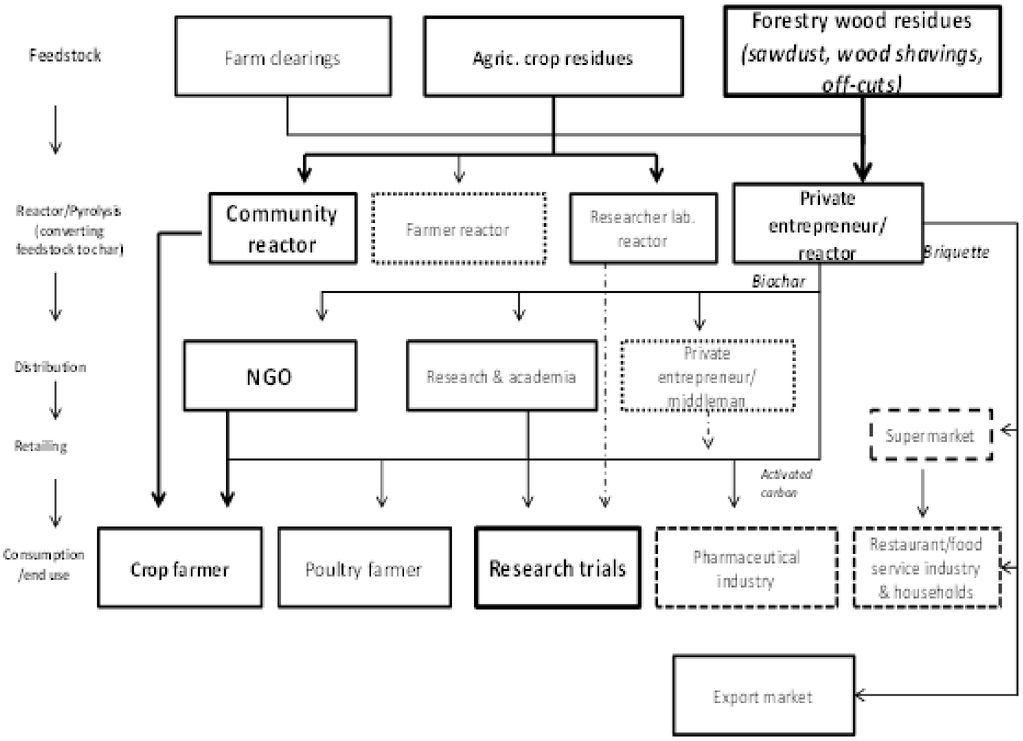

Figure 5: The state of the Ghanaian biochar supply chain

subsidiary products are used by crop and poultry farmers, research and academic institution for their research trials, pharmaceutical industries, restaurants/food service industries and households. Briquette from sawdust is being manufactured and exported to Europe from Ghana by a company, Energy Pool Limited based in Kumasi (Obiri and Nutakor 2011).

Factors influencing biochar adoption

Biochar is not familiar in most farming areas of Ghana. A survey of farmers in four major agro-ecological zones of the country indicated that on the whole, only 25% of the respondents, most of who had been involved in on-farm trials with biochar were aware of the product and its usefulness (Figure 6). However, majority of them perceive it as having the potential for improving soil conditions, especially fertility for improved crop yields (Figure 7).

Assessing the potential for adoption and use among farmers in the Ejura Sekyedumase area, the results from a conditional logit analysis indicates that residential status, farming experience, membership of farmer-based organisation (FBO) and household size may influence the probability of farmers' willingness to adopt biochar technology (Table 6). Natives, Farmers with more years of experiences, small households were most likely to adopt the biochar technology compare to migrant, farmers with less farming experience and large households. Members with FBO's were also found to be less willing to adopt the biochar technology since their focus was more on access to credit rather than in improved soil technologies. The technology was found to have a high rate of adoption if farmers were made aware of its potential benefits when applied as a soil amendment. Promoting it with organic (manure) was also found to be advantageous. There is therefore the need for intensive awareness on the technology, it uses and benefits as a soil amendment (Osei-Adu *et al*., 2015).

Gender issues (mainstreaming)

Generally, biochar adoption may involve the rights of access and control over land for cultivation, money to acquire the biochar

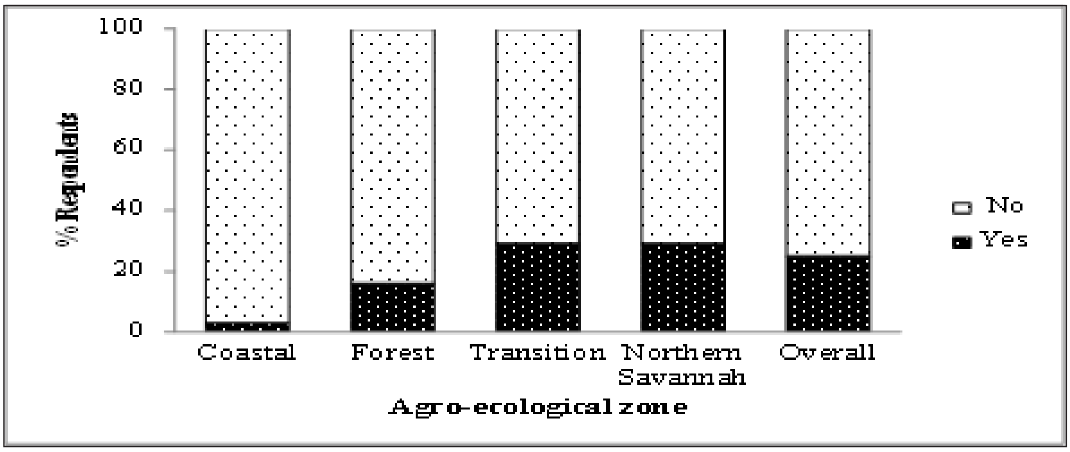

Figure 6: Awareness of biochar technology among farmers
Source: Obiri *et al.,* 2012; Osei-Adu *et. al*., 2015)

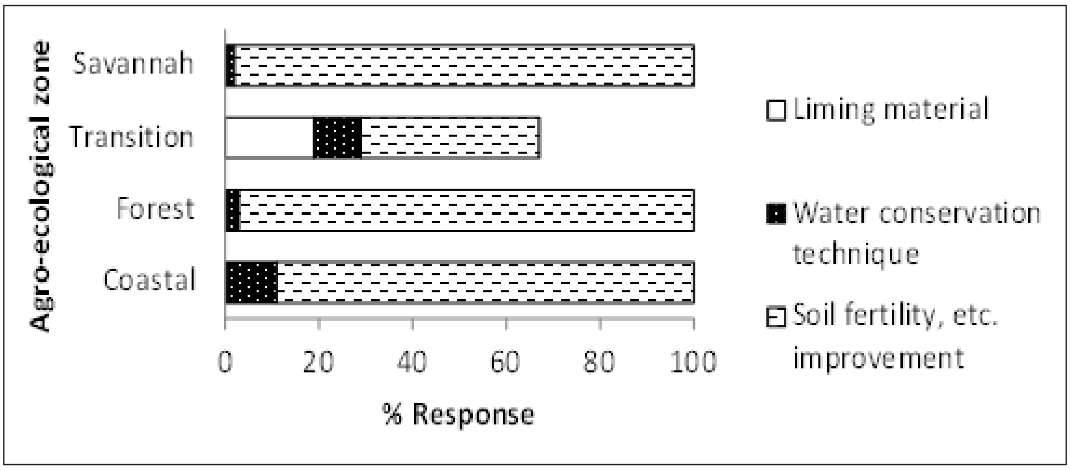

Figure 7: Farmer perception of the function of biochar in crop production
Source: Obiri *et al.,* 2012; Osei-Adu *et. al*., 2015)

Table 6: Conditional Logit Model estimates for socio demographics determinants of willingness to adopt Biochar soil amendment

Variables	Coefficient	SE	P-value
Gender of respondent	-0.244	1.004	0.808
Marital status	-1.334	1.357	0.326
Education experience	-0.001	0.088	0.987
Residential status	2.959*	1.565	0.059
Farming experience	0.076***	0.026	0.003
Participation in training	-0.608	0.659	0.357
Membership of FBO	-2.437***	0.752	0.001
Age of household head	0.016	0.037	0.663
Household size	-0.196**	0.078	0.012
Constant	1.636	1.981	0.409
Log likelihood	74.116		
Cox & Snell R Square	0.438		
Nagelkerke R Square	0.598		

*Note: *** indicates significance @ 1%, ** @5% and *@ 10%*

material and haulage to the farm and labour to prepare land and apply biochar as well as the decision to make this extra investment to enhance soil amelioration for increased yields. A farm level assessment of potential gender disparity in biochar adoption for improving soil productivity in the coastal, forest and northern savannah zones of Ghana revealed that both genders were willing to incorporate biochar into their respective crop production systems (Obiri *et al.,* 2012). This is confirmed by findings on the adoption determinants in section 8.5 above. It was observed that both genders frequently cultivated family-owned land, employ mostly family labour in farm operations although labour may be hired particularly in the forest zone and purchased external inputs including fertilizers and pesticides for farming. However, men tend to be more resourceful than women with respect to owning major equipment (tractor, bullock, motor bike, donkey, protective boots, silo/storage) while women owned mainly hand tools for farming particularly in Northern Ghana. Overall, 54% of the respondents rent machinery (tractor, sprayer, bullock, etc.) and pay for other farm inputs (seeds, fertilizer, etc.). However, only 1% of these were women. Also, men more often rented extra land and some cases leased out land for share cropping Thus assuming biochar is a market commodity, like all other inputs, men will be more likely to take the risk of investing in its adoption.

Conclusion and recommendation

Biochar can contribute to improving crop productivity on smallholdings, although its supply and value chains are not formalized and the product is unfamiliar in most farming communities in Ghana. There is a wide array of potential feedstock for biochar production from agricultural residues as these are generally unutilized except in the northern savannah zone. Generally, across the ecological zones, there are more significant uses for maize cobs for fire than maize stover and these would have to be substituted for, if this material is diverted to biochar feedstock. In the savannah zone potential feedstock from agricultural residues on smallholdings have important alternative uses for fire, compost and animal feed. Biochar production from bush clearings may be encouraged together with maize stover, sheanut and groundnut shells that otherwise may be burnt. The biochar produced could be mixed with compost material to enrich and prolong the productivity of the soil. There is need for trials to recommend appropriate rates and domains for application.

If biochar adoption is not subsidized, its use in crop production at the current market rate of GHC 2000 per ha may be unprofitable particularly among smallholder maize farmers. This is because the value of increased yield from the adoption of biochar could not compensate the additional costs on adoption. Biochar produced from community owned reactor by the farmers yielded higher returns. However, the process is labour intensive, particularly with the haulage of feedstock from distant locations to a central reactor, loading the reactor, monitoring the charring process among others. A conditional logit analysis of willingness to adopt biochar among yam farmers indicated that residential status, farming experience, membership of farmer based organisation (FBO) and household size influenced the probability of adoption. Native (landowners) and well experienced in farming were willing to adopt probably because these are more concerned with sustainability or able to take risks in the extra investments required for adoption. On the other hand tenants, less experienced, large households and those belonging to FBOs were not enthusiastic adopting biochar for reasons explained above. Gender may not constrain biochar adoption. However, rural women are generally less resourceful and are less likely than men to invest in biochar. Efforts at promoting widespread adoption of biochar in crop production would need to consider the following:

- Incentives or subsidies for production and supply to make it cheaper and easily available for use
- Less expensive and labour-intensive production technology options
- Well-illustrated manuals or extension materials to guide production and use on farms
- Promotion of local institutional arrangements that will encourage tenants to adopt biochar especially for shorter duration crops such as maize. This is because the benefit of biochar unlike inorganic fertilizer is derived over a longer period.
- Issues of biochar safety also need to be addressed through testing and standardization.

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