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Effect of Chicken Manure Compost and Okume Wood Biochar on Acid Soil and *Amaranthus cruentus*

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Abstract: Land degradation due to overexploitation and climate change leads to the rapid emergence of research on the use of organic fertilizers in agricultural soils and their effectiveness, particularly in tropical urban garden soils. A field experiment under shelters was conducted to assess the influence of biochar and organic compost on the properties of an urban soil and growth of a leafy vegetable in Libreville. Biochar and compost were mixed with soil in different proportions and *Amaranthus cruentus* commonly cultivated in urban garden of Libreville was used. There were significant increases in pH_w for all compost and combined biochar/compost amendments and in pH_{KCl} for strongest combined biochar/compost amendment. Compost and biochar/compost amendments also increased number of leaves and length of stem of *A. cruentus*. Combined amendments with the highest rate of compost showed greater yields, followed by amendments with compost only and finally of combined amendments with the lowest compost rate. Amendments with biochar only showed any significant difference.

Key words: Biochar · Compost · Soil improvement · Soil fertility · Crop response

INTRODUCTION

Urbanization in the world seems to be unavoidable and according to predictions, by the year 2025 about 70% of the world's population will live in cities. This urban progress is more marked in the developing countries where 2 billion persons previously live in cities. In contradiction of this setting, it is easy to imagine the serious consequences of urbanization for urban planning and the management of urban services [1]. Rapid urbanization in developing countries is correlated with growing needs for food. These needs can partly be met by agriculture in and around cities. Thus, it is often observed that market-gardening farming systems, including leafy vegetables, have recently increased within or near expanding cities [2]. African urban farmers are concerned with maintaining soil productivity and then they use systematically mineral fertilizers. But because of high prices of agricultural inputs and so low levels of nutrient inputs and poor nutrient conservation practices coupled with continuous cropping, soils present a trend of negative balances for nutrients and soil acidification [3, 4]. Now soil is rapidly acidified in all regions where precipitation is high enough to leach appreciable amounts of exchangeable bases from the surface of soil [5]. The situation is compounded by population growth and scarcity of land. On the other part, the majority of the smallholder farmers are not wealthy enough to purchase sufficient mineral fertilizers to replace the soil nutrients exported with harvested crop products and erosion [6]. Organic inputs are often proposed as alternatives to mineral fertilizer.

Applying organic inputs to crop soil not only generates a better nutritional status, but also, positively influences other properties, such as soil particles aggregation, water retention capacity and aeration, contributing to generating high yield, even with a low or zero application of fertilizers [7]. Humans have been recycling organic matter (livestock manure, human waste) in soils for millennia, with positive effects on soil fertility and crop production. Organic amendments occur in many shapes from animal and human waste (fresh, aged, composted) to others wastes, pulp and paper mill sludge and food processing wastes and their charcoal. They are easily available in great amounts required in many land rehabilitation scenarios. The role of organic fertilizers in improving chemical, physical and biological properties of degraded soils is well documented. Soils are resilient and can avail these products mainly through their part in soil organic matter improvement [8].

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Organic amendments supply nutrients and organic matter, presenting much greater options for improving of soil physical, chemical and biological properties, important of the achievement of soil rehabilitation initiatives.

The organic matter and nutrients contained in the solid fraction of bio-wastes can be useful in composting process. This is especially important in areas where soils are deficient in organic matter [9].

Composted material has been extensively studied as an organic amendment for improving soil quality and increasing agricultural production. Generally the studies showed important performance advantages when adding compost resulting from reduction of bulk density of soil, improvements to pore volume of soil and conductivity of the water, the improvement of water retention and reduced soil erosion [10].

More than 80% of urban households in sub-Saharan Africa use charcoal as their main source of cooking energy and the demand is likely to increase for several decades. Charcoal is also a major source of income for rural households in areas with access to urban markets [11].The interest in biochar as soil amendment has risen rapidly over the last ten years. Biochar is rich in C and is produced by heating biomass in a low-oxygen conditions namely pyrolysis [12]. Biochar is seen as a potential long-term regional and/or global climate adjustment / attenuation technique to reduce greenhouse gas emissions, sequester soil carbon, improve soil physical, chemical and biological properties and increase crop yields [13].

Addition of biochar or compost can raise the soil pH and electrical conductivity resulting in a liming effect supplying, hence certain benefits in neutralizing acidic soils. However, this capacity is dependent on both the charge and the conditions of carbonization such as higher pyrolysis temperatures. These phenomena may be the explanation for most of the advantages noted on growth and productivity of plants following the addition of biochar in weathered soils [14-16], but is not systematically observed [15].

Positive effects of the combined use of biochar with organic materials in the fields were recorded mainly in tropical areas in heavily weathered soils where most of the first studies were carried out, often in rural development programs [17].

Regarding their properties and since the pH and electrical conductivity have been reported as a potential index to assess the changes in soil properties and agricultural yields, the interaction between compost and biochar should be further investigated. The aim of the present study is to assess the effects of biochar and compost amendments to an acid soil under amaranth (*A. cruentus* L.) onto soil properties and the quality of plants.

MATERIALS AND METHODS

Study Site and Biochar and Compost Preparation: An amaranth (*A. cruentus* L.) field experiment was conducted in experimental field of Ecole Normale Supérieure of Libreville (0°23'32″ N, 9°27'12″ E). The annual rainfall varies from 1, 500 to 1, 800 mm. Average temperatures oscillate between 25 and 28°C with minima (18°C) in July and maxima (35°C) in April, with an hygrometry of 80 to 100%. Effects of climate change begin to be noticeable in the region. The most significant effect is the duration of the dry seasons sometimes lasting to 5 months in recent years. The predominant soil type is ferralitic soil. Its clays have a weak exchange capacity and there is deficiency of exchangeable bases [4].

The feedstock for biochar production was waste okoume (*Aucoumea klaineana*) wood derived from removal and restoration activities. The biochar was produced using a traditional pyrolysis furnace. Processing of wood required heating temperatures about of 500°C. The biochar was crushed in a mortar, passed through a 2 mm sieve and stored in polyethylene bags.

Ten bags of pig manure mixed with wood chips were composted for four months under shelter. To enhance aeration, the heap was returned then watered every three weeks to maintain moisture to the required level. At the end of the composting process, samples were air dried, crushed in a mortar, passed through a 2 mm sieve and stored in polyethylene bags.

Application of Biochar and Compost in Field Experiment: A field experiment was conducted in amaranth (*A. cruentus* L.) under shelters of Ecole Normale Supérieure of Libreville, Gabon during february-april 2015. The experiments were conducted to investigate the effects of biochar, compost or combined biochar/compost application on the growth of amaranth and changes in soil properties after crop harvest.

The experiment comprised nine treatments in triplicate, where each replicate occupied 2 m^{-2} (1 m x 2 m with a row spacing of 0.4 m). The treatments included: i) control, ii) biochar (BC) at 0.5 kg m^{-2} or 5 t ha^{-1}, BC5, iii) biochar at 1 kg m^{-2} or 10 t ha^{-1}, BC10, iv) Compost (C) at 5 t ha^{-1}, C5, v) Compost at 10 t ha^{-1}, C10, vi) biochar at

5 t ha^{-1}+ compost at 5 t ha^{-1}, BC5/C5, vii) biochar at 10 t ha^{-1}+ compost at 5 t ha^{-1}, BC10/C5, viii) biochar at 5 t ha^{-1}+ compost at 10 t ha^{-1}, BC5/C10 and ix) biochar at 10 t ha^{-1}+ compost at 10 t ha^{-1}, BC10/C10. All the amendments were applied carefully and mixed thoroughly in the soil. The soils were irrigated with water to maintain a proper moisture level of approximately 60% of water holding capacity. The soils were labelled according to their respective treatments and arranged in a completely randomized design with three replications.

The seeds of *A. cruentus* L. were sown on February 3rd, 2015, on a prepared nursery beds, watered regularly using a watering can and checked for seedling emergence. 32 seedlings of amaranth were transplanted into each respective plot two weeks after sowing on February 17th, 2015.

Analysis: The length of the stem and number of leaves of each plant were monitored weekly until March 31th, 2015. From this week, the plants showed flowers and then soils were sampled. Representative soil samples were collected from a depth of 0-15 cm from each entire plot in a zigzag pattern according to standard method. Soil samples were air-dried, crushed in a mortar, passed through a 2 mm sieve and stored in polyethylene bags.

The soil, biochar and compost properties were assessed according to Association Française de Normalisation protocols [18]. They included: the electrical conductivity (EC) and pH in water (pH_w) from a 1:10 soil-water suspension and pH in 1 mol L^{-1} KCl solution (pH_{KCl}) from a 1:10 soil-1 mol L^{-1} KCl solution suspension using pHmeter or conductometer, total organic carbon (TOC) by modified Anne method and total nitrogen (TN) by Kjeldahl method [4]. Analysis was performed before experiment for soil, biochar and compost (pH_w, pH_{KCl}, EC, TOC and TN) and after experiment for soils amended and control (pH_w, pH_{KCl}, EC).

Statistical Analysis: Table and Figures present the results as means ± standard deviation of three replicates. The significance of differences between the means of parameters studied was evaluated by Tukey's test ($P < 0.05$). Statistical analyses were performed with the software XLSTAT, Version 2010 (Addinsoft, Paris, France).

RESULTS AND DISCUSSION

Soil, Biochar and Compost Properties: Table 1 shows the physical and chemical characteristics of experimental soil, biochar and compost. These data were taken before the experiment was undertaken. The pH of the experimental soil was acid (5.7) and the electrical conductivity was 0.39 dS m^{-1}. Organic carbon and total nitrogen content of the soil were very small with values of 11 g kg^{-1} and 1.1 g kg^{-1}, respectively. The pH of compost and biochar were slightly basic (7.8 and 8.3, respectively) and their electrical conductivity (EC) were 2.40 and 0.46 dS m^{-1}, respectively. The organic carbon content of biochar was higher than organic carbon content of compost (869 g kg^{-1} vs 472 g kg^{-1}), while it is the opposite for total nitrogen (5.0 g kg^{-1} vs 13.7 g kg^{-1}). Based on the classification of Landon [19] for agricultural tropical soils, the levels of parameters analyzed showed that soil studied is poor and is not significant for a good agricultural performance.

Soil acidity is one of the major limiting factors to acid sensitive crop production in the tropical countries [20]. The principal use of a fertilizer is to mix it with soil in order to form a good growing medium for plants, for which pH forms a significant criteria of consideration. pH values were 7.8 for compost demonstrating that it was well within the specified range (7.2 to 8.5) in case of compost samples for good quality and mature compost [21]; and 8.3 for biochar demonstrating that biochar could function as a liming agent by instigating an increase in pH of soil and thus growing availability of nutrients and improve nutrient uptake by plants from soil [22]. EC values of soil and biochar are non-saline by soil salinity classification of United States Department of Agriculture (USDA) [23]. Electrical conductivity mean value of the compost samples was 2.40 dS m^{-1}, signifying its high nutrient status and at the same time being securely below (< 4.0 dS m^{-1}) the postulated range for saline toxicity [21].

Effects of Compost and Biochar on Soil Properties: Fig. 1 shows the effect of amendments on soil water pH (pH_w). Biochar addition had no effect on pH_w of soil while compost and mixed compost/biochar significantly increased the pH of soil. In the soil, the addition of compost increased the pH_w by 0.4 units from 5.7 to 6.1 while mixed compost/biochar increased pH_w by 0.6 units. The greatest pH increase was 0.6 units, after addition of compost/biochar 10/10 t ha^{-1} (BC10/C10). Several others have observed an increase of pH in acid soils after mixing with biochar [24-27]. Studies where pH did not change significantly or decreased for biochar amendment are less common [28]. It is probable that the buffer capacity of the acid soil neutralized the biochar alkalinity. An incubation experiment to determine the effects of biochar on the pH

Table 1: Properties of soil, compost and biochar studied

Properties	pH	EC (dS m^{-1})	Organic carbon (g kg^{-1})	Total Nitrogen (g kg^{-1})
Soil	5.7 ± 0.3	0.39 ± 0.01	11 ± 1	1.1 ± 0.2
Compost	7.8 ± 0.4	2.40 ± 0.18	472 ± 29	13, 7 ± 0.5
Biochar	8.3 ± 0.3	0.46 ± 0.10	869 ± 37	5.0 ± 0.2

EC: electrical conductivity

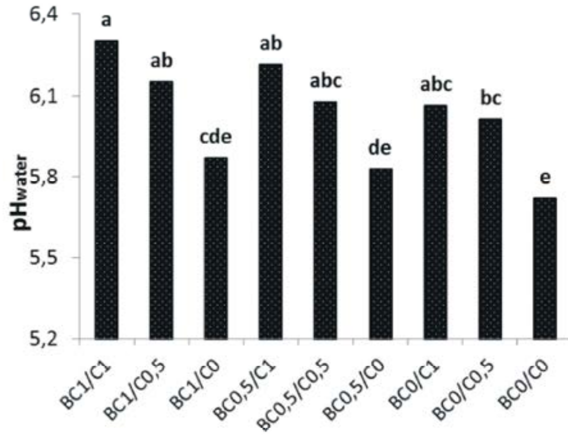

Fig. 1: pH_w after the harvest of amaranth. Different letters indicate statistical difference for harvests at $p < 0.05$

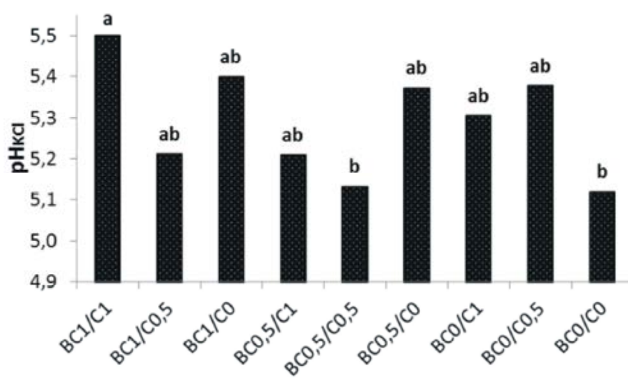

Fig. 2: pHKCl after the harvest of amaranth. Different letters indicate statistical difference for harvests at $p < 0.05$

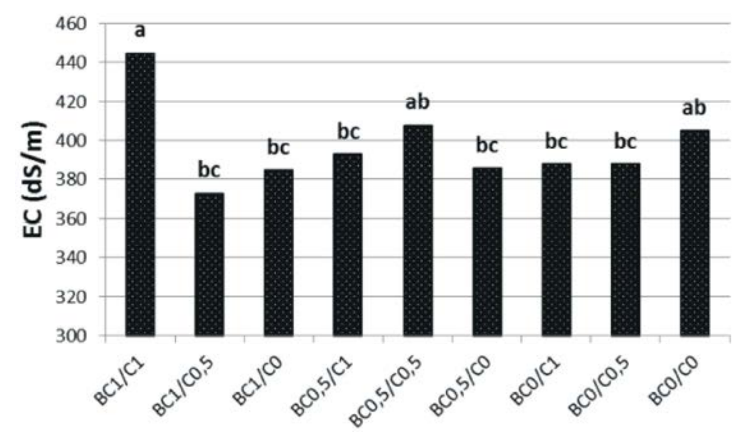

Fig. 3: Electrical conductivity (EC) after the harvest of amaranth. Different letters indicate statistical difference for harvests at $p < 0.05$

of alkaline soils showed that biochar amendment produced acidic components and increased cationic exchange capacity (CEC) of soil. And even, the slow oxidization of biochar in soils can also increase soil CEC, thus enhancing the soil capacity to retain nutrients [29].

Fig. 2 Shows the effect of amendments on soil 1 mol L^{-1} KCl pH (pH_{KCl}). All inputs of compost or biochar significantly increase soil pH_{KCl} but all the amendments combined showed no significant change, with the exception of BC10/C10. The first result is common [30, 31] but the effect of combined biochar/compost on soil pH_{KCl} is not discussed. One would expect to see an increase in pH_{KCl} with all mixed amendments.

Fig. 3 shows the effect of amendments on electrical conductivity of soil. EC values of soil and biochar were non-saline while EC value of compost was very slightly saline by soil salinity classification of United States Department of Agriculture (USDA) [23]. EC value decreased for all amendments, excepted for BC10/C10 where it increased. But changes were not significant, except for BC5/C0. In both soil substrates, biochar and compost mainly contributed to decrease EC values at the ending one vegetation period (Fig. 3). We suppose that nutrient uptake in plants is more likely than leaching because the soil is initially poor. Schulz *et al*. [32] affirm that it is conventional to undertake that plant uptake is higher than leaching of nutrients in composted biochar-amended soils. The high EC value for BC1/C10 would be proof that a good biochar/compost amendment would allow to release for longer nutrients from soil.

Effects of Compost and Biochar on Growth of *A. cruentus*: The result of effect of amendment and cultivation time on number of leaves of amaranth is shown in Fig.4. Number of leaves per plant differed significantly due to the application of different levels of biochar and compost and cultivation time. Generally, the highest mean number of leaves per plant was obtained from BC5/C10 (18.3 leaves per plant) which was statistically identical with BC10/C10 (17.4 leaves per plant), while the lowest number of leaves per plant was recorded from BC5/C0 (5.5) which was statistically identical with BC0/C0 (5.9) and BC10/C0 (6.9). The highest number of leaves per plant (31.0) was observed from BC5/C10 and the lowest (4.6) was recorded from BC5/C0. Number of leaves significantly increased according to the order BC5/C0 ˜ BC0/C0 ˜ BC10/C0 < BC5/C5 ˜ BC10/C5 < BC0/C5 ˜ BC0/C10< BC10/C10 ˜ BC5/C10 ($R2 = 0.598$; $P < 0.0001$).

The result of effect of amendment and cultivation time on length of amaranth stem is shown in Fig. 5. Length of stem differed significantly due to the application of different levels of biochar and compost and cultivation time. Generally, the highest mean of length of stem was obtained from BC10/C10 (20.3 cm), while the lowest number of leaves per plant was recorded from BC5/C0 (2.9 cm) which was statistically identical with BC0/C0 (3.1 cm) and BC10/C0 (4.5 cm). The highest length of stem (42.5 cm) was observed from BC10/C10 and the lowest (1.9 cm) was recorded from BC0/C0. Length of stem significantly increased according to the order BC5/C0 ˜ BC0/C0 ˜ BC10/C0 < BC5/C5 < BC10/C5 < BC0/C10 < BC0/C5 ˜ BC5/C10< BC10/C10 ($R2 = 0.719$; $P < 0.0001$).

The results indicated that combined treatments with 10 t ha^{-1} of biochar generally contributed to the highest values for number of leaves and length of stem of plant when compared to other treatments and the control; followed by treatments with compost only, then combined treatments with 5 t ha^{-1} of biochar. Treatments with biochar only contributed to the lowest values and did not generally enhance amaranth growth when compared with the control. Therefore, biochar in soil reduces number of leaves and length of stem.

Evidence of the beneficial effect of compost on crop yields abounds in the literature: The study showed that the biochar alone had no significant effect on the growth of the plant. Earlier works on poor tropical soils published proofs that biochar amendments to soil increase agricultural production due to the greatest biochar application amounts used in these studies [33, 34]. In an extremely leached Kenyan oxisol, researchers doubled corn production after amendments of 21 t ha^{-1} of biochar over two years [35]. But this advantageous impact of biochar on yield and soil fertility can be a longer-term. Major *et al*. [36] found no difference in productivity for 8 and 20 t ha^{-1} biochar application after twelve months of cropping on a savanna Oxisol in Colombia, but the productivity only increases in the 20 t ha^{-1} biochar application the next forty months. Some biochars can be negative to crop yields, whereas others can increase crop yields [37]. Artiola *et al.* [38] found that the growth of romaine lettuce was unfavorably affected in the 4 t ha^{-1} biochar-amended soil whereas it increased at the 2 t ha^{-1} biochar application rate.

For combined amendments, biochar decreases effect of 5 t ha^{-1} of compost and increases effect of 10 t ha^{-1} of compost on amaranth tissues when compared to compost

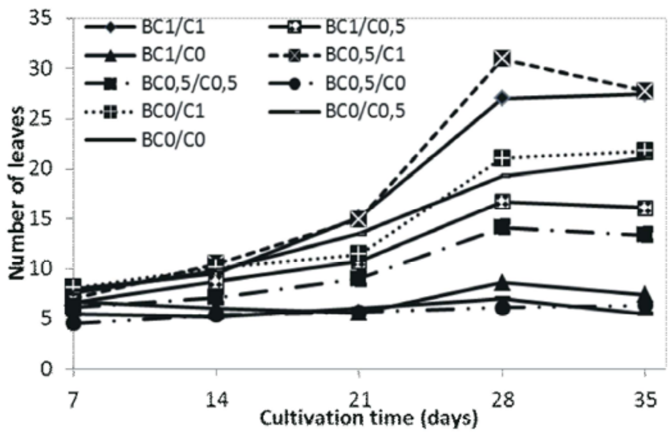

Fig. 4: Effects of biochar, compost and their combinations on number of leaves of amaranth for different cultivation times

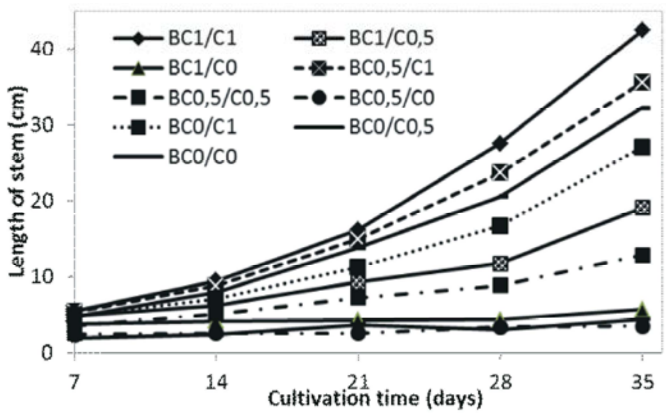

Fig. 5: Effects of biochar, compost and their combinations on length of stem of amaranth for different cultivation times

treatments only. This result shows that there is a biochar limit concentration in the soil from which the biochar/compost amendment is more advantageous than the compost amendment alone. Schulz and Glaser [39] carried out a greenhouse pot experiment to compare biochar, compost and different combinations biochar/compost on growth plant and soil properties. They found plant weights were highest with pure compost application, followed by the biochar + compost mixture. Ghosh *et al*. [40] also carried out a similar study on *Samanea saman* and Suregada multiflora, two common trees in Singapore's urban soils. The *Samanea saman* response to the compost was transitional to those of combined amendments biochar/compost 1/1 and 1/2 (v/v) for the height and girth increments. This might suggest that the effects of organic fertilizers with biochar are specific to category of soil, the environment and plant tissues and species.

CONCLUSION

Use of combined biochar and compost amendments had exerted a positive effect on soil properties and the growth of *A. cruentus*. A significant growth response was found in particularly where compost and combined compost/biochar amendments were applied. There was no significant change with biochar amendment alone. Results of combined biochar/compost indicated that further work is required to identify better mixes to improve plant and soil quality. Future research will also need with biochars and compost of different waste to know their comportment in tropical urban farming given the potential this may have on negating the benefits these amendments have on plant and soil quality. These studies will care out at the longer-term effects of biochar with organic amendments on soil properties and growth of plants and potential effects of high and repeat applications on a wider range of tropical vegetables.

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