International Scholars Journals

African Journal of Soil Science ISSN 2375-088X Vol. 11 (9), pp. 001-009, September, 2024. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Impact of Biochar Application on Waterleaf (*Talinum triangulare*) Growth in Humid-Tropical Forest Soil

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Accepted 20 July, 2024

Waterleaf (*Talinum triangulare*), like many other leafy vegetable is cultivated in home gardens to improve nutritional quality for the family and may provide additional income for female farmers. However, the role of *Talinum* cultivation is often counteracted by declining soil fertility. In recent years, biochar (pyrolysed biomass) has gained importance as a soil amendment tool. However, not much attention has been focused on the influence of biochar on soil quality and plant growth in the humid tropics. This study was conducted to assess different locally available crop waste residues as possible sources of biochar for home garden or small-scale production units of leafy vegetable using Talinum as proxy on highly weathered acid soils in the humid tropics. The experimental set-up was a pot experiment in a complete randomized design in five replicates using biochar sources from cassava stems, rice husk, corncob and sawdust. The results obtained showed that biochar samples had a high cation exchange capacity (CEC), total nitrogen, total carbon and pH (7.8 to 10.8), as compared to the no-input soil (pH 5.7). It is evident that adding biochar to poor and acidic soils could possibly increase the pH and reduce lime requirements. Positive and significant response of biochar ($P<0.05$) application were also observed with the growth, nutrient uptake, and yield of waterleaf. Biochar produced from rice husks obtained the best response followed by sawdust, cassava and corncob. Similarly, the C and N uptake of waterleaf was generally higher with rice husk biochar use as compared to the other treatments. This study has demonstrated that biochar production could be useful in valorizing crop waste residues and biochar use is likely to enhance the productivity of leafy vegetables. More research on possible combination of biochar and other farming strategies such as the application of animal manure and mineral fertilizer to maximize *Talinum* production should be encouraged.

Key words: Biochar, cassava stems, crop waste, residues, nitrogen, soil pH, *Talinum*.

INTRODUCTION

The second half of the last century witnessed a major growth in world population as well as shifts in demands towards more enhanced vegetable consumption and meat-based diets (Satterthwaite et al., 2010; Abdu et al., 2011). This trend has been particularly reflected in a large increase in the urban population in Africa (Predotova et al., 2010). In West Africa, projections indicate that the urban population will reach 63% by 2050, enhancing the needs for effective urban and peri-urban agricultural production systems to complement rural systems (Drechsel et al., 2010). Waterleaf (*Talinum triangulare*) is an important staple leafy vegetable grown in Africa in general and Cameroon in particular (Ndaeyo et al., 2013). Waterleaf cultivation like other leafy vegetables cultivation in home gardens improves nutritional quality for the family and may provide additional income for female farmers. As a result of its high nutritional value that provide good source of crude-protein (22.1%), and vitamins, waterleaf is playing a major role in efforts to eradicate malnutrition in Africa (Tata et al., 2016). In Cameroon, the waterleaf is a major constituent in eru (*Gnetum africanum*), a traditional soup which is consumed alongside other products like gari, and water foufou (Ndaeyo et al., 2013). In addition, urban, peri-urban and rural vegetable including waterleaf cultivation provides a complementary source of income to small-scale female farmers through the supply of fresh vegetables to growing urban markets (Predotova et al., 2010). Waterleaf farming in urban and peri-urban spaces contributes to urban greening and environmental protection (Satterthwaite et al., 2010).

However, the positive impact of the role of waterleaf cultivation on improving small-scale household income and eradication of malnutrition is often counteracted by declining soil fertility and inappropriate nutrient use (Abdu et al., 2011; Ndaeyo et al., 2013). In the acidic soils typical for the humid tropical forest regions, an available plant nutrient such as phosphorus is fixed by aluminum and iron (Bayu et al., 2017). Also, the sorption capacity for water and nutrients depends largely on the organic matter content of the soil (SOM), which is generally low (Njukwe et al., 2014). The additions of organic fertilizers such as animal manures, and compost provide nutrients and can increase SOM content, consequently reduce the needs for inorganic fertilizers and thus production costs (Abdu et al., 2011). But this practice is not economically feasible or environmentally friendly for small-scale female farmers (Amponsah-Daku et al., 2010). The additions of organic fertilizers is also short term as it will be rapidly decomposed and leached below the root level due to the high rainfall (Ngome et al., 2013; Iren et al., 2014).

Pyrolyzed biomass (biochar) on the other hand can be very stable in soils, stabilizing photosynthetic carbon for decades to centuries (Shackley and Sohi, 2010). Biochar is an organic charcoal that is produced by burning organic materials such as agricultural or forestry waste biomass such as rice husk, and corncobs, cassava stems (peelings and cuttings), saw dust, and groundnut husk in an oxygen limited environment (Olivier, 2010; Sohi et al., 2010). The limitation of oxygen in the system prevents the complete combustion of the original waste material but instead produces a carbon rich charcoal (Inyang et al., 2010; IBI, 2016). The concept of producing and using biochar has been based on studies of the terra preta soils found in the Amazon Basin where the ancestral communities of this region deliberately applied burnt organic residues to soils which for hundreds of years has compiled into a thick dark fertile soil (Sohi et al., 2010; Varela et al., 2013). Scientists have studied this carbon rich soils and have shown that applying biochar to soil has multiple benefits, ranging from increase in soil pH, SOM content, the long-term sorption capacity and retention capacity for nutrients and water to increase plant growth and yield (Van Zwieten et al., 2010; Varela et al., 2013).

However, very little is known about the efficiency of nutrient loading and subsequent availability of biochar from different sources in the humid tropical forest soils (Shackley and Sohi, 2010). Understanding of nutrient retention and release mechanisms will provide information on the effective management of plant nutrients to sustain soil productivity and enhance leafy vegetable production (Ndaeyo et al., 2013; Bayu et al., 2017). The aim of the study was to evaluate the morphological response of waterleaf to biochar from different crop waste residue sources in the humid tropics of Cameroon. The study hypothesized that on the acid soils typical in the study area, there will be positive effects on plant growth and yield with application of biochar. The results would represent a significant scientific and practical contribution towards valorization of agricultural waste, stabilization of climate through carbon sequestration and sustainable increase in leafy vegetable production.

MATERIALS AND METHODS

Study location

This study was conducted from September to November 2016 in the Institute of Agricultural Research for Development (IRAD), Nkolbisson experimental filed site (03° 51' N, 11° 27' E and 300 m altitude) in the humid forest Agroecological zone. Nkolbisson has a humid tropical equatorial type climate with four seasons with bimodal rainfall pattern: A long rainy season which is more reliable for crop production lasts from March to June and a short rainy season which lasts from August to November. A long dry season lasts from December to February and a short dry season from July to August. The average annual temperature is 23.5°C and the average annual rainfall is 1670 mm. The soils are acidic and the dominant soil type is rhodic ferralsol with high aluminum and manganese toxicities (Yerima and Ranst, 2005).

Data collection

Production of biochar and soil sampling

Four types of waste residues were selected for this study: cassava

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stems, rice husk, corncob and saw dust (forestry waste). Cassava stems and corncob were pelletized to ensure more comparable conditions (biomass heating rate) in the pyrolysis unit. The different crop waste residues were loosely packed in to a 250 L Elsar UpDraft Pyrolysis Barrel (EUPB) commonly referred to as “e-Barrel” (Hossain et al., 2011). Due to the differences in bulk density between waste residues, the total mass of residues loaded in the barrel differed: cassava stems 32 kg, ricehusk 5 kg; corncob 20 kg and sawdust 9 kg, were respectively used in each pyrolysis experiment. Then, a bit of a starter fluid (kerosene) was spread on the residue in the barrel and ignited using a match stick so that the top can light uniformly (Cantrell et al., 2012). Once the top layer was lit, the circular steel plate was then placed on the e-Barrel and the chimney was added. Shortly, the combustion regime was split into a pyrolysis zone descending in the bed of waste residue (Cantrell et al., 2012). The absence of oxygen in the system prevents the complete burning of the waste residue but instead produces biochar via the process of carbonization. Simultaneously, gas was produced via the process of “gasification” which escapes through the concentrator hole in the chimney. When the pyrolysis process was complete (all the biomass was converted to char), smoke or a red pyrolysis flame was seen illuminating at the bottom of the e-barrel. Afterward, the flame was then extinguished by sprinkling water (Hossain et al., 2011). The pyrolysis temperature was measured using a HANNA HI- 935005 k-thermocouple thermometer (Djousse et al., 2016). The biochar was then ground into small granules, passed through a 2 mm sieve.

Soil samples used in the experiment were collected by using an auger from the upper soil layer (0 to 20 cm) in an experimental field site in Nkolbisson and mixed to form a composite mixture (Adebayo et al., 2011). The samples were then air-dried, finely ground, sieved (< 2mm) and stored in labeled plastic bags and transferred to the laboratory for analyses of pH, cation exchange capacity (CEC) and total nitrogen and organic carbon (ASTM, 2009).

Soil sampling, experimental design and setup

A pot experiment was arranged in a completely randomized design (CRD) consisting of five treatments with five replications. The treatments consisted of biochar from cassava stems (CSb); sawdust (SDb); rice husk (RHb); corncob (CCb); and a control, (normal agricultural practice with no biochar added (NAP)). 1 kg of soil (DM basis), 1 kg of sand and 2 kg of the biochar were mixed and put in 5 L capacity plastic bags (Adebayo et al., 2011). Three seedlings of waterleaf collected from a nearby farmer’s farm, were planted in each pot by vegetative propagation. Water was uniformly applied to all bags every morning and evening. On rainy days, no additional water was applied. The replicates of each treatment were randomly placed in an open field for 2 months.

Determination of growth, nutrient uptake and yield of waterleaf

Over a total period of 2 months, the number of leaves, branches, plant height and leaf surface area of waterleaf plants per pot was measured two weeks after planting on weekly bases.

Plant height was determined as the vertical distance from the ground to the highest portion of the plant. The leaf length was determined by averaging the north-south length of 2 leaves from the intersection with the branch, while leaf width was determined by averaging east-west length from the widest part of the leaf and expressed in cm (Mickelbart and Gosney, 2012). All measurements were made on three individual recently matured and fully expanded leaves. The leaf area was estimated as a product of the length by the width. After harvest, the green biomass (leaf and stem) were removed from the bags, washed free of soil, and weighed for fresh biomass. Samples of the waterleaf from all the treatments were analyzed for TC and TN as per the standard methods.

Data analysis

Biochemical analysis

The chemical properties of the biochar and soil samples studied consisted of total carbon, total nitrogen, pH and CEC. Biochemical analyses of the samples were carried out in the accredited Plant, Soils and Water Analyses Laboratory (LAPSEE) at the Institute of Agricultural Research for Development (IRAD), Yaoundé (Cameroon). The pH of the biochar samples was determined in a 1:5 (w/v) soil: water suspension and measured using a Kent-Taylor glass pH electrode (Asea Brown Boveri, Switzerland) (ASTM, 2009; Ngome et al., 2013); Organic carbon (g.kg) was determined by Walkley and Black wet combustion method (Walkley and Black 1934), while total nitrogen (g/kg) was measured using the Kjeldahl digestion method and analyzed colorimetrically (Buondonno et al., 1995). The cation exchange capacity (CEC) was determined by titrating with 1 M calcium chloride at pH 7, while the organic matter (OM) of soil and biochar were determined as OM = OC x 1.72) (Ngome et al., 2013).

Statistical analysis

The data for various treatment samples, crop parameters and nutrient uptake by plant were subjected to one way analysis of variance (ANOVA), using Statistical Package for the Social Sciences (SPSS) version 17.0. Results were expressed as the mean and their differences were tested for significance. Mean separation was done by Tukey test at 0.05% significant level. Differences of $p < 0.05$ were considered to be significant. Preparation and computation of graphs and tables were done in Microsoft Excel 2010.

RESULTS

Selected properties of the treatments used in the study

The pyrolysis temperature of the biochar samples varied (350°C for ricehusk, sawdust 450°C), corncobs 480°C and cassava 500°C). This however, was due to the moisture content of the crop waste residues (Olivier, 2010; Sandip and Harsha, 2013). The selected biochemical properties of the studied soil and biochar treatments are shown in Table 1. The result from the table indicates that the soil is acidic (pH (H_2O-1:5) 5.68). This shows that, the soil might possibly be deficient of micronutrients such as Co, Cu, Fe, Mn, Zn and macronutrients such as Ca, K, Mg, S, N and P, also the low CEC (cmol.kg) value shows that the total concentration of the major dissolved inorganic solutes (Na^+, Mg^{2+}, Ca^{2+}, K^+, Cl^-, $SO4_2^-$, HCO_3^-, NO_3^- and CO_3^{2-}) in the soil solution is low and this can reduce nutrient availability and consequently low waterleaf yields (Djousse et al., 2016; Bayu et al., 2017).

However, the analyses of experimental materials (Table 1) suggest that, the CEC (12.1 to 39.53 (9.78 $cmol.kg^{-1}$) values of biochar were consistently higher than

Table 1. Selected nutrient composition of the studied soil and biochar samples produced from cassava stems, sawdust, and rice husk and corn cob.

Parameter	Soil (0 to 20 cm)	Cassava stem biochar	Saw dust biochar	Ricehusk biochar	Corncob biochar
pH (H_2O-1:5)	5.68	10.22	9.32	7.79	10.81
Total C (g.kg^{-1})	27.53	93.38	33.11	24.29	35.61
Total N (g.kg^{-1})	0.79	18.15	7.84	4.86	4.17
CEC (cmol.kg^{-1})	9.78	39.53	12.1	16.11	16.98

All values are the average of five replicates.

Table 2. Effect of biochar on selected plant growth parameters of water leaf for week 1.

Treatment	Number of leaves	Number of branches	Plant height (cm)	Leaf length (cm)	Leaf width (cm)	Leaf size (cm^2)
NAP	20.80^{b}	5.20^{a}	1.24^{b}	2.15^{a}	0.67^{a}	1.49^{a}
CCb	31.80^{b}	6.60^{ab}	1.00^{b}	0.68^{b}	0.70^{a}	0.55^{a}
CSb	35.40^{b}	6.40^{ab}	1.38^{b}	1.65^{a}	0.86^{a}	1.43^{a}
SDb	34.60^{b}	6.80^{ab}	0.94^{b}	1.54^{a}	1.00^{a}	1.55^{a}
RHb	53.80^{a}	9.40^{a}	3.02^{a}	2.06^{a}	0.80^{a}	1.64^{a}

The letters a, b, c, compares the means of the various biochar samples. The same letters in a column are not significantly different according to the Tukey test at $p < 0.05$. NAP: Normal agricultural practice (Control); CSb: Cassava biochar, CCb: Corncob biochar, SDb: Saw dust biochar, RHb: Rice husk biochar

that of the soil (9.78 cmol.kg^{-1}) (Sohi et al., 2010). But the highest CEC value (39.53 cmol.kg^{-1}) was recorded in the biochar produced from cassava stems at 500°C. The observed high CEC (cmol.kg^{-1}) values of the biochar could be attributed to the inherent characteristics of biochar crop waste residues. The biochar samples also had a high pH (7.8 to 10.8), while the no-input soil was acidic (pH 5.7). This therefore indicate that the addition of biochar produced from rice husk, saw dust, cassava and corn cob to acidic soils could possibly increase the soil pH and thus reduce lime requirements (Peng et al., 2011; Sohi et al., 2010). However, the high pH of the biochar could be due to an increase in ash content, resulting from the high pyrolysis temperature of 350 to 500°C because ash residues are generally dominated by carbonates of alkali and alkaline earth metals, phosphates and small amounts of organic and inorganic N (Van Zwieten et al., 2010).

Therefore, it is quite logical that the addition of these biochars to soil would drastically increase the soil pH and therefore increase growth and yield of waterleaf. This is in line with Sohi et al. (2010) who reported that soils with higher pH tend to increase nutrient availability by decreasing the quantity of Al+3 and H+ ions in cation exchange sites. The no-input soil had lowest N content (0.79 g.kg-1), total carbon (27.53 g.kg-1), and CEC (9.78 cmol.kg-1). Cassava biochar however, had higher organic carbon content (160.98 g.kg-1) and N content (18.15 g.kg-1) than rice husk biochar (41.87 g.kg-1), indicating lower rate of decomposition and mineralization. The high carbon content of the biochar samples shows thatcarbonizing crop waste residues is likely to increase the carbon sequestration value of the materials (Shackley and Sohi, 2010).

The effect of biochar on the growth parameters of water leaf

Results from the first week of this study revealed that the response of waterleaf to biochar application varied between the various types of biochar (Table 2). Rice husk (RHb) biochar showed a significant effect in increasing the number of leaves and plant height at 5% SL. There was no observable significant difference when biochar from cassava stem, corncob, NAP and sawdust biochar were added. Also, rice husk biochar and NAP significantly increase the number of branches but there was no significant difference between cassava stem, corncob and sawdust biochar. When compared with the other treatments, corn cobs biochar (CCb) appeared to be less effective in affecting the leaf length of water leaf. However, all the treatments did not significantly influence leaf size of waterleaf in the first week of the study.

During the second week of the study (Table 3), there was a large significant difference for ricehusk biochar. A significant increase in the number of leaves was observed with the application of sawdust and ricehusk biochar to the soil.

All treatments including rice husk biochar resulted in significantly higher ($p < 0.05$) values for number of branches than observed in the control. Concerning the

Table 3. Effects of biochar on water leaf plant growth parameters for week 2.

Treatment	Number of leaves	Number of branches	Plant height (cm)	Leaf length (cm)	Leaf width (cm)	Leaf size (cm^2)
Nap	23.60^{b}	5.4^{b}	2.00^{b}	3.03^{cb}	1.37^{ab}	4.37^{ab}
CCb	25.2^{b}	6.40^{ab}	1.50^{b}	2.35^{cb}	0.91^{cb}	2.14^{cb}
CSb	31.20^{b}	6.60^{ab}	2.32^{b}	3.22^{ab}	1.40^{ab}	4.58^{ab}
SDb	33.60^{ab}	7.60^{ab}	1.82^{b}	2.22^{c}	0.68^{c}	1.67^{c}
RHb	46.20^{a}	9.80^{a}	4.32^{a}	4.08^{a}	1.58^{a}	6.47^{a}

The letters a, b, c, compares the means of the various biochar samples. The same letters in a column are not significantly different according to the Tukey test at $p < 0.05$. NAP: Normal Agricultural practice (Control); CSb: Cassava biochar, CCb: Corncob biochar, SDb: Saw dust biochar, RHb: Rice husk biochar.

Table 4. Effects of biochar on plant growth parameters of water leaf for week 3.

Treatment	Number of leaves	Number of branches	Plant height (cm)	Leaf length (cm)	Leaf width (cm)	Leaf size (cm^2)
NAP	29.4^{b}	6.3^{b}	3.46^{b}	3.85^{a}	1.42^{ab}	5.53^{a}
CCb	32.6^{ab}	6.6^{ab}	1.14^{c}	2.43^{c}	1.04^{ab}	2.57^{b}
CSb	33.8^{ab}	6.8^{ab}	2.72^{cb}	3.75^{ab}	1.46^{ab}	5.88^{a}
SDb	34.6^{ab}	7.6^{ab}	2.74^{cb}	2.75^{cb}	0.95^{c}	2.27^{b}
RHb	47.0^{a}	9.4^{a}	6.10^{a}	4.71^{a}	1.75^{a}	8.27^{a}

The letters a, b, c, compares the means of the various biochar samples. The same letters in a column are not significantly different according to the Tukey test at $p < 0.05$. NAP: Normal Agricultural practice (Control); CSb: Cassava biochar, CCb: Corncob biochar, SDb: Saw dust biochar, RHb: Rice husk biochar

plant height, all treatments showed good performance, even though there was no significant difference between the treatments at $P < 0.05$. It can be seen that little response in the leaf length leaf width and leaf size was observed with the application of biochar from saw dust and no significant differences were found between treatments for the cassava stem biochar and the control. As compared to cassava biochar and NAP, corn cob biochar appeared to be less effective in increasing the leaf size of waterleaf in the second week of the study. In week 3, biochar from ricehusk was significantly different from all the other treatments in all aspects of waterleaf growth parameters (Table 4).

There was no significant difference between biochar produced from cassava, corncob and sawdust on the number of leaves and branches at $P < 0.05$. There was however, a significant difference between the control and the other treatments. Biochar from cassava and sawdust did not significantly influence plant height and leaf length; although, plant height and leaf length tended to decrease between corncob biochar and control. The absence of significant difference between the treatments could be due to a large variability of the results. Also, corncob, cassava and sawdust biochars did not significantly increase the leaf width of waterleaf. There was however a significant decrease in leaf width for sawdust at $P<0.05$. This could be due to the use of all available nutrients by 2 and 3 weeks as a result of the small nutrient content of biochar which varies with the biomass source, and the pyrolysis temperature as reported by Djousse et al. (2016). Water leaf size was significantly increased by sawdust and corncob but there was no statistical significant difference between biochar from cassava stems and control. The results suggest that ricehusk biochar is more efficient than the other biochars.

Effects of biochar on fresh weight ($g.kg^{-1}$) of waterleaf

The mean values for the biomass measurements on the fresh weight of waterleaf treated with four types of biochar are shown in Figure 1. When the physicochemical characteristics of the biochar are considered, results of this study showed that waterleaf plants responded well in acidic soils amended with ricehusk biochar, suggesting the ability of biochar produced from rice husk to increase the fresh weight of waterleaf (16.29 $g.kg^{-1}$). There was no apparent significant effect from the control and biochar from other crop waste biomass sources.

Varela et al. (2013) reported that soil pH affects the availability of nutrients and how the nutrients react with each other. From the results of the present study (Table 1), biochar pH (H_2O) of 6.0 to 8.0 provides ideal conditions for plant production and pH above 8.5 may be toxic. At a low pH, beneficial elements such as

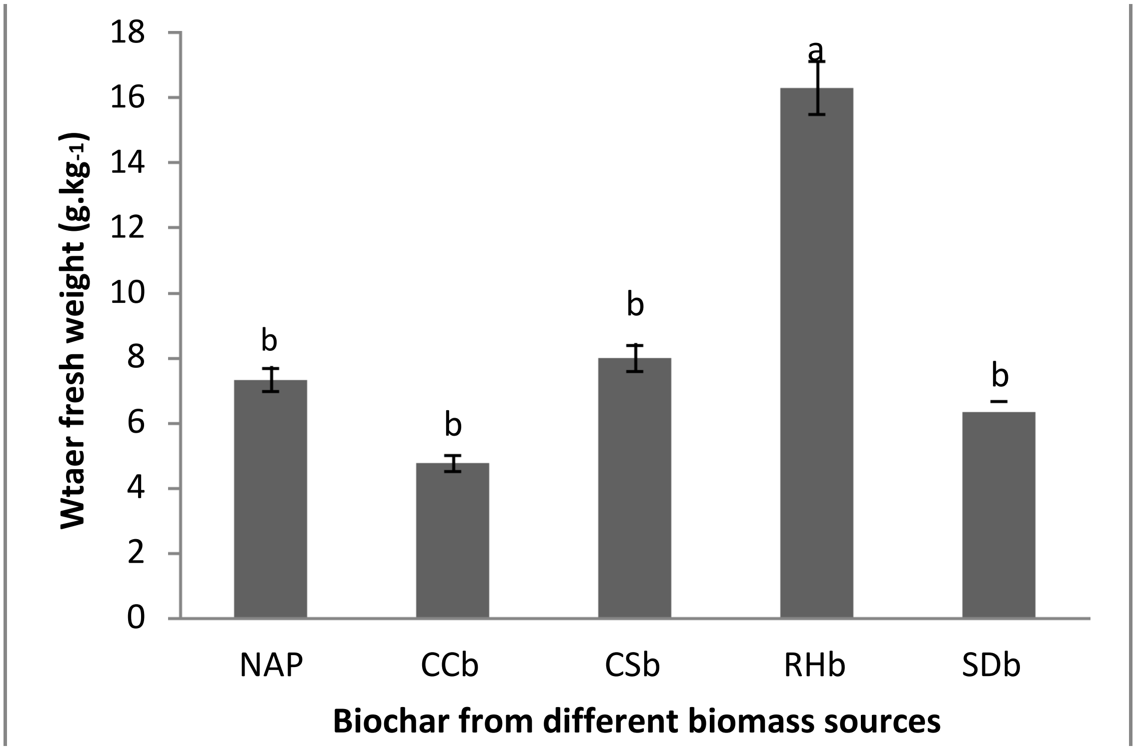

Figure 1. The effect of biochar from different biomass sources on fresh weight of waterleaf. The letters a, b, c, compares the means of the various biochar samples. The same letters in a column are not significantly different according to the Tukey test at p<0.05. NAP: Normal agricultural practice (Control); CSb: cassava biochar, CCb: corncob biochar, SDb: saw dust biochar, RHb: rice husk biochar.

molybdenum (Mo), phosphorus (P), magnesium (Mg) and calcium (Ca) become less available to plants. Other elements such as aluminium (Al), iron (Fe) and manganese (Mn) and may reach levels that generate phytotoxicity to plants (Lake, 2000). In contrast, the low fresh weight of waterleaf from soils amended withcassava, and corncob biochar may be due to the high pH of the biochar (pH 10.81 and 10.22, respectively). These results are in line with Lake (2000) and Schulz and Glaser (2012) who reported that when the pH (H_2O) is greater than 7.5, calcium can bind to phosphorus, making it less available to plants. Additionally, alkaline soils have also been reported to cause zinc and cobalt deficiencies that lead to stunted plants, poor growth and reduced yields in some crops (Lake, 2000) as may have resulted. Based on the study of Kimetu and Lehmann (2010), the Si and ash content of ricehusk is much higher than in saw dust, corncob and cassava. Although, the detailed effects of Si, ash, K and surface area were not studied, these physiochemical parameters of ricehusk biochar changed the soil structure and provided optimum fertilizing conditions for the test plant. According to Cantrell et al. (2012), biochars produced at higher temperatures were less effective at promoting aboveground productivity because high-temperature biochars tend to be alkaline and contain less biologically active volatile compounds that can otherwise limit plant growth (Haefele et al., 2011). Therefore in this study, high-temperature biochars such as cassava and corncob biochar are also more resistant to decomposition and would, rather be better candidates to fulfill the carbon sequestration benefits than increase plant growth (Hossain et al., 2011).

Effects of biochar types on total C and N uptake by waterleaf

Total carbon in the waterleaf increased significantly(P<0.01) with the application of rice husk biochar (RHb) (Figure 2a). Although, NAP had a lower value, 20.80 g.kg^{-1}, the differences was not significant at P<0.05 as compared to the other biochar treatments applied.

The use of biochar therefore, is a promising technology that could be promoted for the long term improvement of total carbon content and therefore the soil organic matter in the study area (Major et al., 2010). As shown in Figure 2b, the quantity of nitrogen uptake in the waterleaf was also significantly influenced by the application of rice husk biochar and control but not in the corn cob, cassava and saw dust biochar. Nitrogen uptake as affected by biochar significantly increased (P<0.05) from 6.40 to 9.40 g.kg^{-1} N/ha, in the waterleaf. According to reports by DeLuca et al. (2009), nitrogen is an essential plant

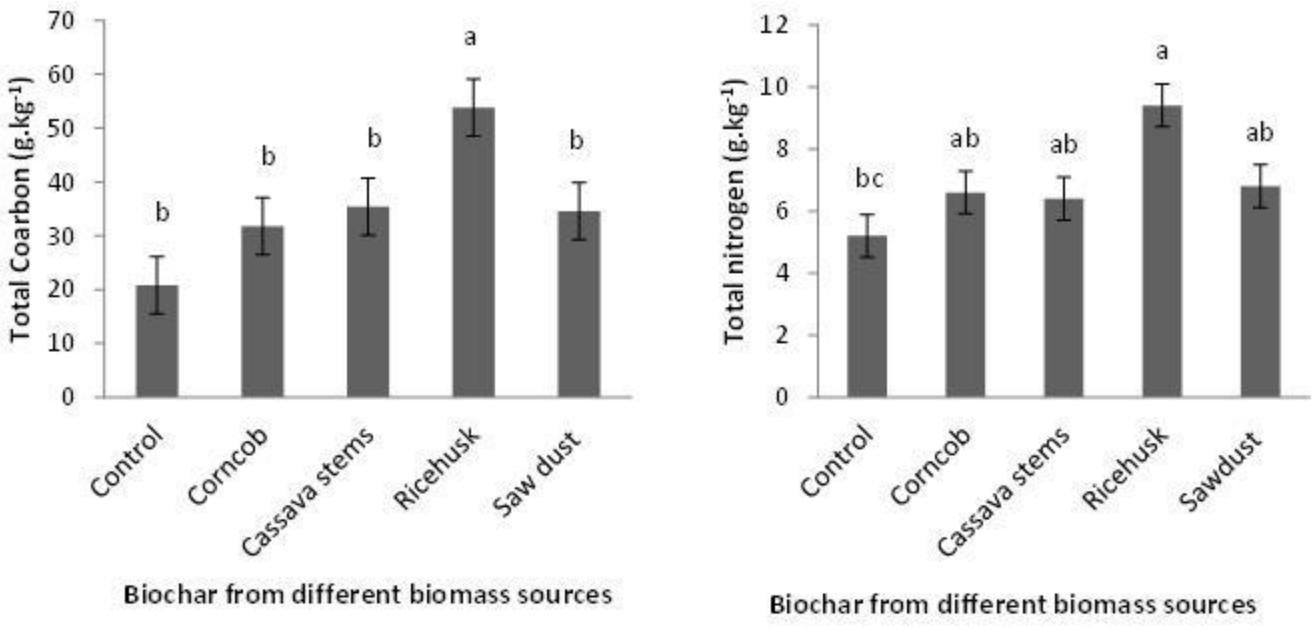

Figure 2. The effect of biochar from different biomass sources on total N and C uptake by waterleaf. The letters a, b, c, compares the means of the various biochar samples. The same letters in a column are not significantly different according to the Tukey test at $p<0.05$. NAP: normal agricultural practice (Control); CSb: cassava biochar, CCb: corncob biochar, SDb: saw dust biochar, RHb: rice husk biochar.

nutrient and the addition of biochar to soils stimulates microorganism activity in the soil, potentially affecting the soil microbiological properties. As soil biota is responsible for biotic fixation of atmospheric nitrogen and nitrogen mineralization, the application of biochar to soils improves the physical and chemical environment in soils, providing microbes with a more favorable habitat (Krull et al., 2010). This consequently, aids in the transformation of nitrogen held in organic forms (humus and decaying plant and animal matter) to forms available for uptake by plant roots, potentially improving its availability to plants (Sandip and Harsha, 2013).

DISCUSSION

Significant effects were observed on waterleaf tissue N and C concentrations. Significant effects of biochar application were also observed whereby the growth, nutrient uptake, yield and dry matter production of waterleaf was higher for rice husk biochar and delayed for saw dust, cassava and corncobs biochars, respectively. In the present study, the C and N uptake of waterleaf generally excelled by the application of biochar, implying that to sustain waterleaf cultivation in the humid forest zones of Cameroon, management strategies to improve soil quality such as the use of biochar could probably be the most efficient (Ibeawuchi et al., 2007; Tagoe et al., 2008). The consistent increases in the growth and yield of waterleaf by plants treated with rice husk, cassava, saw dust and corn cobs biochar over the control in this study is an indication that these organic amendments were able to supply the essential nutrients for good growth and yield of waterleaf (Iren et al., 2014). The results also showed that some types of biochar such as ricehusk biochar with low pH have potential in increasing the growth and yield of waterleaf, which can be used in home garden applications. However, other types of the biochar such as corn cobs can decrease the waterleaf weights due the high pH which causes nutrient deficiencies (Mickelbart et al., 2012). The high cation exchange capacity and nutrient retention capacities of the biochars also contributed to the waterleaf plant ability to absorb plant mineral nutrients such as calcium, phosphorus, potassium and nitrogen present in soil throughout the growth period (Inyang et al., 2010). The results of this study have shown that the addition of biochar improved soil chemical properties, growth and yield of waterleaf and is therefore recommended for sustainable production of waterleaf as well as in promoting health and safety as well improve the environmental sustainability of vegetable production systems. The study also showed that, field soils in the humid tropics may benefit from some reduction in soil pH through incorporation of organic amendment such as ricehusk biochar (Mickelbart et al., 2012).

In the humid tropics of Cameroon, agriculture is characterized by a large number of small-scale vegetable farmers with the high use of mineral fertilizer (NPK 20:10:10) to increase soil nitrogen (Ngome et al., 2013). The smallholder waterleaf farming have also been characterized by a low level of resource utilization, low levels of productivity, and returns to labor and capital investment (Ibeawuchi et al., 2007). A shift towards safe eating habits by consumers consuming food crops produced with organic fertilizers has been observed particularly in the humid tropical forest regions due to the increasing awareness of tropical diseases such as diabetes, hypertension, cancer, metal poisoning and obesity associated with the consumption of food produced with chemical fertilizers (Iren et al., 2015). In these areas, the acceptance of a crop is influenced by the type and source of nutrients used in its production. Generally, in developed countries, vegetables produced using organic fertilizer attracts higher prices than the same quantity produced using inorganic fertilizers because it is believed that the former is devoid of synthetic chemicals (Ater et al., 2011). Thus, according Kookana et al. (2011), the valorization of crop residues to biochar and introduction into smallholder vegetable cropping systems is suggested for restoring soil nitrogen in the vegetable farms as well as modifying the environmental fate, bioavailability, and efficacy of nutrients in soil (Tagoe et al., 2008).

Conclusion

The biochar types examined in this study showed potential in increasing the growth and yield of waterleaf. Although, yield increases were not significant, the treatments examined did not compromise vegetable productivity. The type of crop residue, composition and pyrolysis temperature may be responsible for the varying results. For higher effects on increasing growth and yields, these biochar types could be applied in combination with essential farming strategies such as use of leguminous cover crops, animal manure and mineral fertilizer. More research on possible combinations of biochar and other agronomic strategies to boost vegetable crop productivity in forest zones of Cameroon is therefore encouraged.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

The authors express their sincere thanks to the C2D PAR project, MINRESI and IRAD for financial and material support, to Mama Theresa Ngome for providing the waterleaf cuttings and the staff of LAPSEE of IRAD Nkolbisson for the biochar and soil analyses.

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