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Effect of Biochar Issued from Crop Wastes on the Yield of Variety 8034 Cassava in the Humid-Forest Agroecological Zone, Cameroon

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***Abstract*— *Cassava is an important food crop cultivated (75%) by smallholder farmers. However, yields are very low and rarely exceed 17tons/ha^{-1}. A study was carried out at Nkolbisson in the humid forest zone (HFZ) of Cameroon to assess the effect of three types of biochar issued from Cassava (CSb), Ricehusk (RHb), and Corncob (CCb) on the root yield of variety 8034 cassava cultivated along a soil fertility gradient. The biochars were produced using an Elsa pyrolysis technology with carbonisation time of 50-58mins and temperature ranging from 400-650 ^{0}C. Twelve 8m^{2} plots were constructed in three sites from the higher elevated, moderately elevated and flat fields. The biochars were applied at 20t.ha^{-1}in three replications in a completely randomized design. Results showed that the biochars were high in nutrients containing 4.17-18.15 g.kg^{-1} N, 22.26-42.51 mg.kg^{-1} P, 2.48-4.18 cmol.kg^{-1} K and pH (H_2O: 7.78-10.81) and were significantly higher than the no-input soil containing 0.79 g.kg^{-1} N, 7.41 mg.kg^{-1} P, 1.42 cmol.kg^{-1} K and pH (5.68). Cassava root yield was significantly higher ($P < 0.05$) in RHb plots (23.22 t.ha^{-1}) than CCb (20.53 t.ha^{-1}), CSb (18.67 t.ha^{-1}) and the no-input soil (16.13 t.ha^{-1}). The addition of biochar particularly RHb, increased nutrient uptake in cassava leaves and roots compared with the no-input soil. The study concludes that biochars with higher N, P and K content tend to increase cassava root yield and suggests increasing the quantity of biochar to 40t/ha^{-1}or continuous application in combination with other farming options such as poultry manure, compost or mineral fertilizer to maximize cassava productivity given the benefits of biochar*.

Keywords*— *Acidic soils; Biochar; Food security Improved cassava; Nitrogen; Pyrolysis technology

I. INTRODUCTION

Since 1970, research institutes in Africa have been developing and releasing improved cassava varieties that are high yielding (30-40 t.ha^{-1}), low in cyanide content and resistant to pest and disease (Mapiemfu et al. 2017). The improved variety 8034 cassava (*Manihot esculenta* Crantz) is a versatile cassava variety (Temegne et al. 2016; Mapiemfu et al. 2017). Compared to other cassava varieties, 8034 is most widely cultivated (60%) because it is renowned for its resistance to cassava mosaic diseases (CMD), high average yields between 30-45 t.ha^{-1} of fresh roots with a dry matter content of approximately 35-38% (IRAD, 2016). The cassava variety can also be transformed in to a variety of processed products including starch, *miondo*, *bobolo*, flour for bread production and feed for ruminant consumption (Mapiemfu et al. 2017). The leaves provide valuable source of proteins and vitamins in the diets of Cameroonians and many other tropical countries (Papa *et al*. 2013; Temegne et al. 2016). Therefore the 8034 cassava variety could be effective in combating mineral deficiencies, hunger and malnutrition (Tata et al. 2017). For optimum growth, cassava requires a moist, warm climate with temperatures ranging from 26 to 28°C and steady annual rainfall of 1.600-4.000 mm (Papa et al. 2013). But poor annual rainfall may be offset by favorable soil characteristics, including soil pH 6-8.5 (Araki and Sarr 2013). Generally, soils (rhodic ferralsol) of the humid forest agroecological zone of Cameroon are acidic (pH <5units) and characterized by low soil organic matter and base saturation which results in low water/nutrient retention capacity (Ngome et al. 2013; Papa et al. 2013). The soil nutrient levels are also very low aggravated by Mn and Al

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toxicities which limit P-availability to plants due to fixation by aluminum, iron and calcium (Kanmegne 2004; Papa et al. 2013).

Although cassava can grow on low fertile soils, continues cassava cultivation without adequate soil nutrient management predominantly in the humid forest agroecological zone of Cameroon has led to continues decline of cassava productivity (Araki and Sarr 2013; Ngome et al. 2013). The decline in cassava yields has been attributed mainly to soil fertility decline, insect pests, diseases and the use of low-yielding varieties (Temegne et al. 2017; Mapiemfu et al. 2017).Therefore, a minimal amount of nutrient input in particular nitrogen is required for an optimum cassava growth and tuber yield (Ngome et al. 2013). In the traditional system which predominates in the area, average cassava tuber yields are very low rarely exceeds 17 t/ha^{-1} (Temegne et al. 2017). Technologies to enhance soil fertility are poorly adopted probably because technology recommendations rarely take into consideration the climatic and site conditions such as soil type and resource availability within the environment. This therefore underlines the need for site-specific targeting of technology options to improve cassava productivity in the humid forest agroecological zone of Cameroon.

Biochar is a carbon rich compound that is produced by pyrolysis (thermal decomposition) of waste plant-based biomass under controlled low-oxygen conditions (Major et al. 2010; Kung et al. 2015; Billa et al. 2017). Biochar has been proposed for the correction of soil nutrient deficiency and acidity (Kimetu and Lehmann 2010; Keith et al. 2013; Djousse et al. 2016). Studies have shown that soil fertility attributes (C and N pools and available P), cation-exchange capacity (CEC), and soil pH of poor nutrient and acidic soils were enhanced by adding biochar produced from crop waste (Dotaniya et al. 2016; Djousse et al. 2016). The subsequent improvement of plant productivity has also been attributed to reduction in soil bulk density, increase in microbial activity and water-holding capacity (Steiner et al. 2011; Baronti et al. 2014; Kung et al. 2015). But very few studies have investigated the use of biochar for cassava production in humid forest region soils (Islami et al. 2011; Mapiemfu et al. 2017). Smallholder cassava farmers are also not aware of the use of biochar as a soil amendment for crop production (Islami et al. 2011).

Food crops such as rice (*Orita sativa*), cassava (*Manihot esculenta*), and maize (*Zea mays*) generate waste such as corncob, and ricehusk where it is openly burned in the field after harvest or abandoned in large quantities to decompose naturally around processing mills in urban areas. Little or no attention has been given to the impact on the environment. Also no deliberate attempt has been put in place to effectively utilize the waste, or safely dispose it off. Whereas, these crop wastes contain appreciable quantities of soil nutrients such as N, P, K which if converted to biochar could offer both agronomic and climate change mitigation benefits. Therefore, the main objective of this study was to comparatively assess the effect of three types of biochar produced from crop wastes; Cassava (CSb), Ricehusk (RHb), and Corncob (CCb) on variety 8034 cassava growth, yield, nutrient uptake and soil fertility attributes (C and N pools and available P).

II. METHODOLOGY

Site location and experimental design

The field experiment was conducted during 2016/2017 farming seasons at the Nkolbisson in the humid forest agro-ecological zone with bimodal rainfall of Cameroon. The area is characterized by equatorial climate with a bimodal rainfall pattern, consisting of four seasons: Long rainy season from September to November, short rainy season from March to June; a long dry season from December to February, and short dry season from July to August. The dominant soil type is the rhodic ferralsol which are generally acidic, low in organic matter and deficient in exchangeable bases by (Yerima and Ranst 2005). During the period, an average rainfall of 1700 mm, daily temperature ($24^{O}C$) and relative humidity of 97% was recorded (IRAD 2016).

The experimental field site was further divided in to three sections of 2 km apart following a soil fertility gradient from the higher elevated, moderately elevated and flat fields. Then 4m x 2m subplots were plotted out in each section. Each section had four plots of $8m^2$ giving a total of 12 plots for entire study covering a surface area of $234m^2$. The flat field section (lower part of a stream) was where irrigated vegetable production takes place in the dry season. In the higher and moderately elevated area, crop cultivation (e.g. maize, bean and cassava) takes place only in the rainy season. The vegetation at the higher elevation section comprised mainly *Chromolaena odorata*, the moderately elevated section was dominated by *Panicum maximum* and *Imperata cylindrical*, while flat area was a mosaic of *C. odorata*, *P. maximum I. cylindrical* and few trees. There were four experimental treatments consisting of three biochars arranged in a completely randomized (CRD) design with three replications. The fourth treatment without biochar (Ctr) (control) was maintained to serve as reference.

Soil sampling and preparation

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Soil sampling was also conducted to determine the suitability of the soils. Soils with low pH (< 6 units), low nitrogen content (< 2 g/kg^{-1}), and available phosphorus content (< 15 mg/kg^{-1}) were required for the study (Agoyi et al. 2017). Top soil samples (0-20 cm depth) were collected from five locations inside each experimental plot in the three sections using an auger following a zigzag pattern. The soil samples were bulked to form a composite sample, then air dried and sieved with 2mm sieve, after which sub-samples of 5g each were weighed and subjected to the following chemical analysis; pH (H_2O), total nitrogen, organic carbon, exchangeable bases (Na^+, K^+, Mg^{2+}, and Ca^{2+}) and available phosphorus.

Biochar production

The biochar was produced from three most common crop waste (corncob, ricehusk and cassava stems) using an Elsa barrel pyrolysis technology under field conditions (Billa et al. 2017). These crop wastes were selected based on their availability, accessibility, environmental and health concerns in the study area. The wastes were collected from farms and rice mills around the city. No permit was required to collect the waste biomass.The Elsa pyrolysis barrel used was composed of a 250 litter capacity metal cylinder which was opened on one end with perforations to supply secondary air required for combustion (Annex 1). Equally, the closed end was also perforated for supplying primary air. A removable cover steel plate was also perforated with additional brass fittings for chimney. The crop wastes (feed stock) were then packed in the barrel depending on the density (Annex 1). The top of the feedstock in the barrel was ignited with a glowing match stick and the circular steel plate was then placed on the e-Barrel with the chimney. Shortly, the combustion regime splits into a pyrolysis zone carbonising the feed stock as it descends to the closed end. The low oxygen in the system prevents the complete burning of the residue and produces biochar via the process of carbonization. After 45 to 50 minutes when all the feedstock biomass had been converted to biochar, the biochar was then poured directly on the well laid out experimental plots. The flame in the biochar was immediately extinguished with water (Annex 1).

Plant Material

The plant material used in this study consisted of an improved variety 8034cassava collected from the Institute of Agricultural Research for Development (IRAD). This variety was selected following farms trials in the area and based on desirable traits, including resistance to diseases and pests, high root yield stability (30-40 t/ha^{-1}), food quality, and plant architecture which prevents weed. The biochar produced from waste cassava stem and roots (CSb); ricehusk (RHb); and corncob (CCb) were applied at 20 t/ha^{-1} i.e. 2 kg/m^2 by surface spreading on the experimental plots and mixed with the soil to 20 cm depth using a hand hoe. Then healthy cuttings (25-30 cm in length) with at least 4-5 nodes was planted in late May 2016 on 30cm high ridges constructed in the 4x2 m^2 plots giving a planting density of 1 plant/m^2. The cuttings were planted in such a way that 2/3 of the cutting was below ground and 1/3 above ground level with a 45° inclination. Manual weeding was carried out as required. The plants were harvested at twelve months after planting. No mineral fertilizer was used and the experiment was carried out under natural rain fed conditions. Thus 16 kg of each biochar were applied per plot and each plot had 8 cassava plants presumably enough for a cassava canopy.

III. DATA COLLECTION

Measuring plant growth parameters

Plant growth parameters were determined at 3, 6 and 9 months after planting following methods of C2D IRADPAR Cassava (IRAD 2016). Plant Height was determined by measuring from the base of the plant to the apex of the longest leaf of three randomly plants selected cassava plants per plot using a metre rule. Root length was determined at harvest by measuring from the crown to the end of the root with a metre rule. Root girth was measured immediately after harvest at 2cm from the crown using a venier caliper. Root yield was determined following the formula of Mapiemfu et al. (2017). Roots weighing above 35g were selected from each plot and weighed to estimate the marketable root weight, while Non-marketable roots consisted of roots weighing less than 35g (Mapiemfu et al. 2017).

Laboratory Analysis

Analysis of the biochar, soil and the cassava root and leaves was carried out in the Soil and biochemistry laboratory of the Faculty of Agronomy and Agricultural Science (FAAS) of the University of Dschang, Cameroon. The samples were finely ground to pass through a 0.5 mm sieve and oven dried at 105 ^{O}C to constant weight. Biochar and soil pH (H_2O) was determined in a 1:5 (w/v) soil: water suspension. Total C was determined by chromic acid digestion and spectrophotometric analysis (Heanes 1984). Walkley and Black (1934), chromic acid titration method was used to determine the soil organic matter. Total N was determined by wet acid digestion and analyzed by colorimetric analysis (Buondonno et al. 1995). Available P was extracted using Bray-1 procedure and analyzed using the Molybdate blue procedure (Bray and Kurtz 1945; Murphy and Riley 1962).

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Exchangeable cations (Ca, Mg, K and Na) were extracted using the ammonium acetate (NH_4OAC) and analysed by flame atomic absorption spectrophotometry (ASTM 2009). Cation Exchange Capacity (CEC) was calculated using the regression equation (CEC = 3.024 x Org. C + 2.05) from the organic carbon (%) proposed by Araki and Sarr (2013).

Statistical analysis

The measured parameters were analysed statistically using SPSS 17.0 software. The relationships between the parameters were determined by linear regression analysis (Dytham, 2011). Increase in cassava root yield (ton/ha^{-1}) was considered as the dependent variable while the independent variables included; the type of biochar (Cassava, Ricehusk and Corncob) applied and the nutrient composition of the biochar. The linear regression model used is shown in the equation below (Dytham, 2011).

$Y = \beta$ Thus, $Y=\beta 0 + \beta_1 X_1 + \beta_2 X_2 + \mu$

Where;

Y = Dependent variable (Cassava Root yield measured in ton/ha^{-1})

β = The regression parameter (unknown coefficients of each independent variable)

μ = The error term; X= Independent variable

- X1: The type of biochar used (Cassava, Ricehusk, and Corncob)
- X2: Nutrient composition of the biochar (TN, TC, SOM, Mg, Ca, and P).

Tukey test at 0.05% significant level was used to separate means. Differences of $p < 0.05$ were considered to be significant. The study results were presented as percentage distribution tables, bar graphs and pie charts using the Microsoft Excel 2010.

IV. RESULTS AND DISCUSSION

Physico-chemical characteristics of the soil

The characteristics of the soils at the experimental site and biochar used are presented in table 1. The result of the analysis showed that the soil at the experimental site was acidic, low in organic carbon content, total nitrogen, and poor in exchangeable bases (Table 1).

From table 1 above, the soil type was compact sandy clay rhodic ferralsol with red color. Such soil lack adsorptive capacity for basic plant nutrient and may be susceptible to erosion and runoff menace (Ngome et al. 2013; Temegne and Ngome 2017). With the absence of rock fragments (boulders) in the subsurface soils, it may permit available water capacity in direct proportion to their volume. The soil pH (5.6) was moderately acidic (Table 1). The pH condition of the soil could be attributed to the high rainfall (3500mm per annum), which increases leaching of basic cations (Ca, K, Na, and Mg) from the soil *solum* (Sohi et al. 2010). This may also be due to increase in albeit hydrogen and aluminum (Al), iron (Fe) and manganese (Mn) concentrations which are the principal contributors to exchangeable acidity in soils (Van Zwieten et al. 2010). According to USDA (2016), such soil condition can induce phosphate fixation and reduce the ability of microorganisms to fix atmospheric nitrogen. The low level of organic matter content (47g.kg^{-1}) may be attributed to intensive land cropping and natural settings (Temegne and Ngome 2017). Therefore, such level of organic matter content could hardly sustain intensive cassava production and other crops in the ecological zone. Total nitrogen contents were low with mean value of 0.79g.kg^{-1}. This value is below 2 percent established for productive soils in the zone and therefore cannot sustain intensive crop production. The low level of total nitrogen could be attributed to N mineralization due to rapid microbial activities, leaching of nitrates and crop removal (Agbede et al. 2010; Temegne and Ngome 2017).

The value for available phosphorus was also low with mean value of 7.15mg.kg^{-1} (Table 1) which is lower than the critical level of 15 mg/kg^{-1} in most tropical soils (USDA, 2016). Exchangeable bases were also low with Ca content of (1.45 cmol.kg^{-1}), Mg (7.21 cmol.kg^{-1}), Na (0.41cmol/kg^{-1}) and K (1.42 cmol.kg^{-1}). With these low levels of exchangeable bases, the soils lack adsorptive capacity for nutrient and indicate very poor soil fertility with very low nutrient mobility (Temegne and Ngome 2017).

The Cation Exchange Capacity (CEC) was generally low (<10 cmol/kg^{-1}) in the soils with mean values of 9.78 cmol/kg^{-1} (Table 1). This low value is indicative of salinity which negatively affects the P mineralization from organic matter decomposition. Therefore, a minimal amount of nutrient input from organic fertilization is required for sustainable and optimum cassava growth and root yield.

Description of morphological characteristics of the variety 8034 cassava

The leaf, stem and root morphological characteristics of 8034 cassava variety in the biochar and non biochar treatment plots are shown in Table 2.

From Table 2, 100 % of cassava plants in all treatment plots had green purple unexpanded leaf color within the first three months after germination. The Cassava plants in plots amended with ricehusk and corncob biochar recorded the longest petiole length (Table 2) which showed reddish green coloration compared to the other treatment plots with yellowish green petiole color. Sensory analysis with 4 farmers and 3 market women showed that over 90% of the cassava roots harvested mostly from the biochar plots had sweet taste. These findings are similar to the studies reported by Mapiemfu et al. (2017) for the 8034 cassava variety. The study showed that biochar can influence the variation in morphological characteristics existing among cassava varieties that could be exploited to enhance cassava breeding programs.

Influence of biochar on the plant growth of 8034 cassava variety

Significant differences in cassava plant leaf, and stem parameter were observed amongst the various treatments as shown in Table 3. Observation of Table 3 shows that the cassava plants in the corncob, ricehusk and cassava biochar treatments recorded a steady growth and were significantly different ($P < 0.05$) from the control plots (no biochar). The number of leaves in the biochar amended plots (corncobs and ricehusk) was significantly higher ($P < 0.05$) than the control. The stem girth and plant height in all biochar amended plots were significantly higher ($P < 0.05$) than the control (Table 3). The RHb treatment produced the tallest plants followed by CCb treatment. This could be explained by the differences in the nutrient and organic matter content in the biochar (Islami et al. 2011) which resulted in increased water and nutrient retention capacity of the soil and hence improved the growth of cassava (Baronti et al. 2014). The values recorded from the ricehusk biochar amended plots might also be due to the fast nutrient (Ca, P and Mg) released due to its low porosity and surface area thereby giving cassava plants better rapid shoot growth, energy storage and development according to findings of Kimetu and Lehmann (2010). According to Weyers and Spokas (2014), organic matter decomposes releasing significant quantities of N and P more quickly in warm humid climates which is essential for plant vegetative growth. Also, available P is released faster in well aerated soils than on saturated wet soils. Soils with inherent pH values below 5.5 limit P-availability to plants due to fixation by iron, aluminum, or calcium while pH values between 6 and 7.5 are ideal for P-availability. Table 3 further reveals that, there were no significant difference ($P > 0.05$) in the length and width of leaf lobe, length of petiole and height to first branching between the biochar treatments and the control. But the biochar treatments had significantly higher values than the control (Table 3). The low values recorded in the cassava and corncob biochar treatment compared to the ricehusk biochar treatment might be due to the low rate of release of nitrogen, phosphorus and potassium in the biochar according to Elad et al. (2012). Studies have shown that adequate P levels in soils enhances vigorous shoot and root growth, promotes early maturity, increase water use efficiency and cassava root yield while P deficiency reduces cassava yield by stunting vegetative growth, delay maturity, and restricts energy storage and utilization by the cassava plant (USDA, 2016). Therefore, applying biochar alone or mixed with other organic amendments such as poultry manure, and compost could result in significant increase in cassava plant growth.

Influence of biochar on root growth of 8034 cassava variety

Significant differences in cassava root growth parameters were observed amongst the various treatments during the 2016/2017 farming season as shown in Table 4. Results from Table 4 revealed that the application of biochar issued from ricehusk and corncobs significantly increased ($P < 0.05$) the number cassava roots, root girth (cm) and weight (kg). Ricehusk biochar (RHb) produced the longest cassava roots (52.98 cm) but were not significantly different ($P > 0.05$) from the other treatments. Plots treated with biochar issued from corncobs statistically gave significant higher number of marketable roots and yields despite the fact that the cassava mosaic disease severity was high in the treatment. However, the study is in line with Islami et al. (2011) who reported that soils enriched with biochar increased pH from 5.8 and 7.0 and supplied essential nutrient that produce smooth and cassava larger roots. This shows that the addition of biochar issued from ricehusk and corncobs probably released ammonium ions which increased the pH and thereby reduced the soil acidity which played a major role in the production of healthy cassava roots. Also, increase in exchangeable Mg and Ca due to biochar addition might have improve available P uptake by reducing Al^{3+} and Mn levels asserted by (Islami et al. 2011). Therefore, cassava plants growing under biochar plots were able to make use of the available P and nutrients in the soil resulting in higher marketable roots than the control. The high number of non-marketable roots harvested in CSb and control treatment might be due to acid nature of the soil and the slow release of nutrients by cassava biochar due to high C recalcitrance (Rajkovich et al. 2012; Guo and Chen 2014). One can therefore conclude from this study that the use of biochar as organic amendment appears effective in improving cassava growth and is strongly recommended to smallholder cassava farmers provided they have enough biochar to apply in their farms.

Influence of biochar on 8034 cassava Root yield (t/ha^{-1})

The mean weight of variety 8034 cassava harvested from each treatment plot was expressed as kg/per plot and then extrapolated to ton per hectare (Figure 1).

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From Figure 1, the cassava root yields ranged from 16.13-23.22 t/ha^{-1} with RHb treatment recording the highest cassava yield (23.22 t/ha^{-1}) and was significantly different ($P < 0.05$) from CCb (20.53 t/ha^{-1}), CSb (18.67 t/ha^{-1}) and the control (16.13 t/ha^{-1}). These results were, higher than the FAO average cassava yield estimates of 12.8 t/ha^{-1} (FAOSTAT, 2011). Islami et al. (2011) reported significant increase in cassava root yields due to the application of biochar produced from poultry manure in the first year of application. Major et al. (2010) also reported significant increase in maize yield observed as due to N, P and K uptake efficiency resulting from biochar application (Major et al. 2010). According to Saglam and Dengiz (2017), the addition of biochar may have increased the total porosity which decreased bulk density and in turn favors root penetrability. This improved the exploration of soil nutrient by plants roots for better growth and yield (Saglam and Dengiz, 2017).

Temegne et al. (2016) also observed that the addition of poultry manure and different fertiliser types improve soil physical properties including bulk density, moisture and increased absorption of nutrients in soil by plants which led to increase in the yields of cassava crops. Therefore, the addition of organic amendment such as biochar played a similar role. The average yield obtained from the control plot was similar to the 12.67-15.34 t/ha^{-1} obtained in smallholder cassava farmer's field by Mapiemfu et al. (2017) in the same area. This was probably due to the very infertile and acidic ferralsol (soil pH 5.6). Similarly, average rainfall in the study site ranged between (1600-2000 mm per year) and was sporadic which though increases water availability for plant growth decreases nutrient availability through soil erosion, runoff and excessive leaching particularly in the elevated and moderately elevated sections (Mapiemfu et al. 2017). The long dry season periods also reduced water availability explaining the low yield achieved in the control treatment compared to the CSb, CCb and RHb treatment (Figure 1). Therefore the higher yields of 8034 cassava variety (Figure 1) in the ricehusk biochar amended plots were probably due to decrease in soil acidity and increased water/nutrient retention efficiency (Islami et al 2011; Weyers and Spokas 2014). Therefore, as local cassava varieties are easily attacked by disease, dissemination of improved varieties as well as the use of ricehusk biochar technology to smallholder cassava farmers is important to maintain sustainable cassava productivity.

Effect of crop waste biochar on nutrient uptake of variety 8034 cassava

The nutrient content in the leaf and root of TMS 8034 cassava variety is presented in Table 5.

From Table 5, the RHb and CCb recorded the highest P, K^+, Ca^{2+}, and Mg^{2+} content of cassava leaves and were significantly higher than CSb and the control. However, N contents of cassava root from all the biochar amended plots were significantly higher ($P < 0.05$) than the control. In conclusion, variety 8034 cassava growing biochar amended plots show better foliar assimilation of P, K^+, Ca^{2+}, and Mg^{2+} than cassava plants growing on the no biochar input soils (Table 5). The high K^+, Ca^{2+}, and Mg^{2+} content in the cassava leaves when compared with other legume plants confirm their importance as rich nutrient source of dietary minerals food and nutrition security (Emmanuel et al. 2012;Morgan and Mingan 2016).The N content in cassava roots harvested from ricehusk biochar plot was higher than in corncob and cassava biochar amended plots. This could be attributed to increase in N supply through rapid decomposition or increased N retention against leaching losses that presumably improved N use efficiency (Bertin et al. 2013; Agoyi et al 2017). Based on reports of Enders et al. (2012) and Guo and Chen (2014) on the molecular mechanism for the recalcitrance of biochar, one can conclude that the low nutrient content observed in the cassava roots harvest from the CSb treatment (Table 4) could be explained by the recalcitrant of the carbon in the biochar. The interactive effects of carbon and silicon components could have influenced the slow decomposition of the cassava biochar by microbial activities (Guo and Chen 2014).

Influence of biochar on the nutritional content of 8034 cassava

Both the roots and leaves of cassava are consumed as they provide a balanced nutritional value, as a source of carbohydrate, crude fiber, vitamins and minerals (Emmanuel et al. 2012; Tata et al. 2017). The analysis of nutritional value in root variety 8034 cassava harvested from soil amended with biochar is presented in Figure 2.

In Figure 2a, the crude protein (CP) content ranged from 24.2 g/kg^{-1} in the control plot; 25.2 g/kg^{-1} in RHb; 26.8 g/kg^{-1} in CCb to 23.6 g/kg^{-1} in CSb plot respectively. But the average crude fibre (CF) content recorded from the biochar plots was 25.2 g/kg^{-1} higher than the control (24.2 g/kg^{-1}). The protein content values are similar to those obtained for the variety 8034 cassava by Mapiemfu et al. (2017). Cassava is very low in fats and protein than in cereals and pulses. Nonetheless, it has more protein than other tropical food sources like potato, yam and plantains (FAOSTAT 2011; USDA 2017). The Young tender cassava leaves have been shown to provide good source of dietary proteins, vitamin-K and valuable B-complex which play a major role in the strengthening of bones and relieve of Alzheimer's disease responsible for neuronal brain damage (Emmanuel et al. 2012). However, the prolong consumption of cassava products may lead to chronic illness such as tropical ataxic neuropathy (TAN) and Diabetes (USDA 2017). Therefore, the differences in crude protein levels were probably due to the nutrient composition of the different types of the organic material used (Rajaie and Tavakoly 2016).

In Figure 2b, the crude fibre (CF) content was higher in the biochar amended than the control (13.3 g kg^{-1}) plots with RHb recording the highest value of 13.8 g kg^{-1} followed by CCb (13.7 g kg^{-1}). The lowest values recorded from the CSb plots (12.8 g kg^{-1}). This could be due to the recalcitrant nature of the biochar which was influenced by the high pyrolysis temperatures during the production process (Annex 1).

Figure 3a and b presents the percentage of carbohydrate content in variety 8034 cassava harvested from soils amended with biochar issued from crop waste. The carbohydrate content (Figure 3a) did not differ significantly (P > 0.05) amongst the treatments but cassava harvested from CSb plots had the highest carbohydrate content (39.49 %), followed by RHb (33.01 %), CCb (31.79 %) and control (31.44 %). The mean carbohydrate content in biochar plots was 34.76% higher than the control with (31.44 %). These values are in line with those of Adepoju and Nwangwu (2010) and Richardson (2013). These differences could be due to the inherent characteristic of the 8034 variety or the increase in the nutrient levels of minerals that synthesizes carbohydrates in the soil due to the application of biochar (Islami et al. 2011). There was which is important for cassava productivity in the study area.

Figure 3b shows the gross energy (kcal) in TMS 8034 cassava variety harvested from three different types of biochar amended plots in the humid forest agroecological zones of Cameroon. The highest gross energy (kcal) of TMS 8034 was observed from CSb plot (130.34 kcal) and was significantly different (P < 0.05) from RHb (114.78 kcal) and CCb (115.78 kcal) and control (112.23 kcal) (Figure 4b). The significantly high value recorded in the CSb treatment could be due to the high organic matter and carbon content in the biochar. Cassava is one of the highest value calorie starch-rich roots and tuber crop. A 100 g cassava root provides about 160 calories according to USDA (2017). The calorie value is due to the breakdown of amylose and sucrose which accounts for more than 17 % and 69 % of total carbohydrate sugars.

Regression analysis on the influence of biochar cassava yield and soil characteristics

A regression test was done to establish if there was any cause to effect relationship between independent factors (biochar) and increase in cassava production in terms of yields as depicted in Figure 5. The high cassava root yield could be attributed to high starch synthesis and translocation activities stimulated by increased levels of N, P and K in the soil by biochar. The data in Figure 5 indicates that there was a strong positive relationship between the different types biochar applied and increase in cassava root yields (r=0.83**), on the other hand, a strong and positive relationship between root yield (ton/ha^{-1}) and nutrient content (0.77**) were also observed (Figure 4).

Figure 4 depicts that cassava root yield (ton/ha^{-1}) markedly increase with increase in the nutrient composition of the biochar. The intercept of 16.95 showed that if soil acidity could be reduced, more nutrients would be available to the cassava plant for starch production and therefore yield would increase considerably (Mehdi et al. 2017). The mechanisms of the effects of pH on the growth, 8034 cassava root yield and nutrient uptake in different treatments are complex, because a negative correlation between pH and yield is often associated with a positive correlation between organic carbon and yield (Papa et al. 2013). This means that high organic matter content in soil reduces acidification by supplying nitrogen and basic cations that stabilizes the pH (Fermont et al. 2010). Whatever the mechanisms, the improved 8034 cassava variety was able to adapt better the acidic soil conditions. This indicates that the soil pH and organic carbon content is an important soil fertility attribute in the soils of Nkolbisson of the humid forest agroecological zone and an important determinant of cassava yield. Biochars issued from ricehusk (RHb) was better in promoting growth and yield compared to biochar issued from cassava and corncobs probably because it contained more K than N (Table 1). Never the less, a high N from mineral or organic fertilizer application stimulates excessive foliage production but poor root development in the plants (Dkhil et al. 2011; Ukaoma and Ogbonnaya 2013). This means that that ricehusk biochar released nutrients readily in soils increase cassava root yield as the crop absorbed higher rates of K from the soil (Ukaoma and Ogbonnaya 2013; Mehdi et al. 2017). In addition to its role in photosynthesis, K facilitates the circulation and the transfer of sugars and amino acids to the

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storage roots (Dkhil et al. 2011). Phosphorus on the other hand is essential in promoting root development thereby promoting nutrition and plant growth (Fermont et al. 2010; Temegne et al. 2015).

It was also observed that the biochar amended plots were less infested by weeds than the control plots. This was probably due to rapid vegetative growth that facilitated canopy closure which certainly suppressed the growth of weeds (Fermont et al. 2010). Crop canopy closure also helps to reduce soil erosion and competition for soil nutrients between the plant and weeds (Temegne et al. 2017). Therefore, the use of ricehusk biochar should be the recommended soil fertility management option in the humid forest agroecological zones as well as the arid and semi-arid regions as biochar application will decrease soil acidity permitting crops to access more nutrients in soil that will result in higher yields. There was therefore the need to emphasize on farmer education through on-farm promotion efforts given the benefits from the production and use of biochar.

V. CONCLUSION

The main reason for the low cassava root yields in the area was the non-existing soil fertility and nutrient management in particular the lack of nitrogen and soil acidity. If this situation is not improved, all other innovation (herbicides, pesticides, drought and disease resistant varieties and irrigation) are condemned to fail. Cassava yields were significantly higher in the biochar amended plots particularly in the ricehusk biochar treatment than control plots. This study has led to the conclusion that biochar with higher N content tend to increase cassava root yield. The study suggests that increasing the quantity of biochar applied to 30t/ha^{-1} and 40t/ha^{-1}or continuous application in combination with other farming options such as poultry manure, compost or mineral fertilizer to maximize cassava productivity and improve the efficiency of biochar as a soil amendment should be encouraged in the humid forest agroecological zones.

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CONFLICT OF INTEREST

The authors have not declared any conflict of interests

INFORMED CONSENT

Authors declare that this study has not been published or submitted simultaneously for publication elsewhere.

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Annex 1 Production of Biochar from Crop Waste Using the Elsa Barrel Pyrolysis Technology


Rice husk


Corn cob


Cassava waste cuttings


a. Barrel filled with crop was


b. Fire is set from the top


d. Fitting the chimney


e. Carbonization process


f. Measuring temperature


g. Biochar


h. Applying biochar on plots


i. Cassava cuttings on heaps

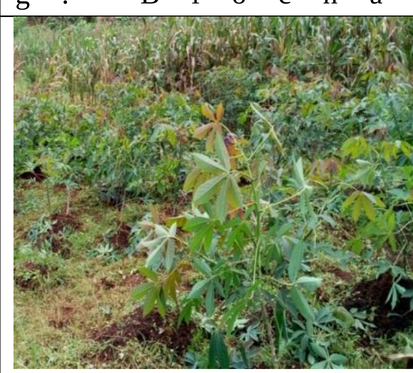
j. Cassava growing on biochar plots

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Table.1: Characteristics of the Soil and Biochar used in the Experimental Site

Parameter	**Soil (0-20cm)**	Cassava	Corncob	Ricehusk
		Biochar		
pH (H_2O-1:5)	5.67^{c}	10.23^{a}	10.91^{a}	7.81^{b}
CEC (cmol.kg^{-1})	9.49^{c}	39.53^{a}	16.98^{b}	16.11^{b}
Total C (g.kg^{-1})	18.14^{c}	93.38^{a}	35.61^{b}	24.29^{bc}
Total N (g.kg^{-1})	0.79^{c}	18.15^{a}	4.17^{b}	4.86^{b}
Organic Matter (g.kg^{-1})	47.46^{c}	160.98^{a}	61.40^{b}	46.95^{bc}
Available P (mg/kg^{-1})	7.15^{c}	13.71^{b}	12.81^{b}	16.26^{a}
Mg (g/kg^{-1})	1.09^{c}	9.98^{a}	6.43^{bc}	7.73^{b}
K (g/kg^{-1})	3.54^{c}	5.41^{a}	4.16^{b}	4.48^{b}
Na (g/kg^{-1})	2.09^{c}	4.63^{b}	5.45^{a}	3.13^{c}
Ca (g/kg^{-1})	1.82^{c}	11.63^{a}	7.83^{b}	10.83^{a}
Sand %	39%	-	-	-
Silt%	15%	-	-	-
Clay%	46%	-	-	-
Type of toxicity	Al	-	-	-

The letters a, b, and c compare the means of the soil and biochar samples. The same letters in a row are not significantly different according to Tukey test at $p < 0.05$.

Table.2: The Morphological Characteristics of the Variety 8034 Cassava in the Different Treatments

	Parameter	**Morphological traits**			
		Control	Cassava biochar	Ricehusk biochar	Corncob biochar
1	Color of unexpanded leaf	Green purple	Green purple	Green purple	Green purple
2	Pubescence	Pubescence	Pubescence	Pubescence	Pubescence
3	Shape of central leaf lobe	Lanceolate	Lanceolate	Lanceolate	Lanceolate
4	Color of Petiole	Yellowish green	Yellowish green	Reddish green	Reddish green
5	Growth habit of main stem	Straight	Straight	Straight	Straight
6	Color of main stem	Silver green	Silver green	Silver green	Silver green
7	Presence of flowers and fruits	Present	Present	Present	Present
8	Color of root cortex	Cream white	Cream white	Cream white	Cream white
9	Taste of root sap	Intermediate	Sweet	Sweet	Sweet

Table.3: The Growth Parameters Variety 8034 Cassava in the Different Treatments

Crop waste biochar	**Number of leaves**	**Length of leaf lobe (cm)**	**Width of leaf lobe (cm)**	**Petiole length (cm)**	**Height to first branching (cm)**	**Stem girth (cm)**	**Plant height (cm)**
Ctl	22^{b}	15.57^{ab}	5.16^{a}	20.53^{a}	69.40^{ab}	22.40^{b}	177.82^{b}
CSb	23^{b}	16.59^{a}	5.28^{a}	20.91^{a}	47.12^{b}	23.61^{ab}	193.78^{ab}
RHb	37^{ab}	16.00^{ab}	5.28^{a}	23.27^{a}	81.89^{a}	30.12^{a}	235.70^{a}

CCb	44^{a}	16.29^{a}	5.29^{a}	22.12^{a}	97.03^{a}	23.78^{ab}	209.26^{ab}

Ctr: Control; CSb: Cassava biochar; CCb: Corncob biochar, RHb: Rice husk biochar. The letters a, b, c, d, e and f compare the means of the various biochar samples. The same letters in a row are not significantly different according to Tukey test at $p < 0.05$

Table.4: Root growth parameters of variety 8034 cassava in the different treatments

Crop waste biochar	**Number of roots**	**Number of MR**	**Number of NMR**	**Root length (cm)**	**Root girth (cm)**
Ctl	3.51c	1.67bc	4.83a	28.28b	45.45b
CSb	3.72b	1.44c	3.33b	30.55b	43.84b
RHb	6.53a	1.89 b	1.33c	32.53a	52.98a
CCb	5.52ab	2.33a	2.33b	27.18b	53.60a

Ctr: Control, CSb: Cassava biochar, RHb: Ricehusk biochar; CCb: Corncob biochar. MR: Marketable roots; NMR: Nonmarketable root. The letters a, b, c, d, e and f compare the means of the various biochar samples. The same letters in a row are not significantly different according to Tukey test at $p < 0.05$

Table.5: Nutrient Composition of Cassava Leaf and Root of Variety 8034 Cassava Harvested from the Different Treatments

Plant nutrients	***Cassava Leaf***				***Cassava Root***			
	Ctr	*RHb*	*CCb*	*CSb*	*Ctr*	*RHb*	*CCb*	*CSb*
Total N ($g.kg^{-1}$)	-	-	-	-	1.22^{c}	2.82^{a}	2.51^{b}	2.33^{b}
Av. P ($mg.kg^{-1}$)	29^{b}	39^{a}	38^{a}	37^{a}	60^{b}	130^{a}	130^{a}	120^{b}
Ca^{2+} ($cmol.kg^{-1}$)	1.62^{b}	2.51^{a}	2.32^{a}	2.12^{b}	0.63^{b}	1.23^{a}	1.34^{a}	1.13^{a}
K^{+} ($cmol.kg^{-1}$)	1.32^{b}	1.56^{b}	1.64^{a}	1.41^{b}	3.91^{ab}	7.32^{a}	8.74^{a}	5.62^{ab}
Mg^{2+} ($cmol.kg^{-1}$)	0.92^{b}	0.24^{b}	0.26^{b}	0.48^{a}	0.21^{b}	1.51^{a}	1.42^{a}	1.33^{a}

Ctr: Control, CSb: Cassava biochar, RHb: Ricehusk biochar; CCb: Corncob biochar. The letters a, b, c, d, e and f compare the means of the various biochar samples. The same letters in a row are not significantly different according to Tukey test at $p < 0.05$

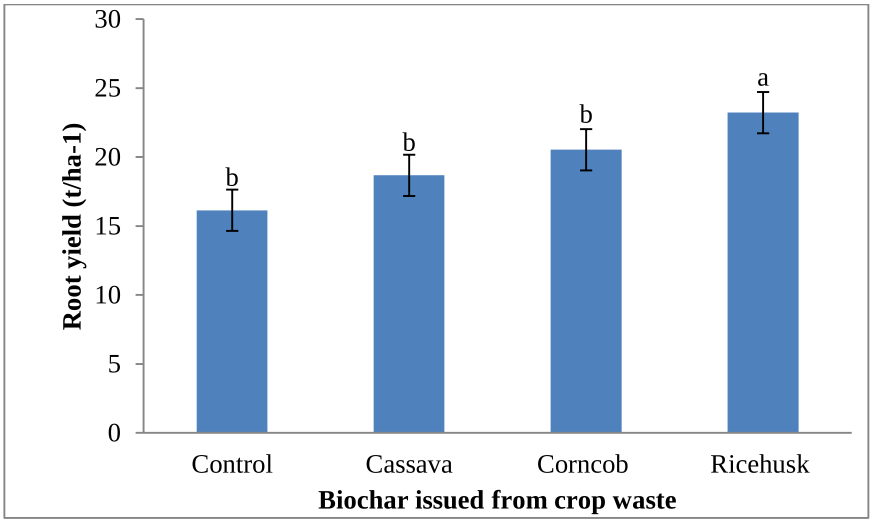

Fig.1: Cassava Tuber Yield (t/ha^{-1}) as Influenced by Crop Waste Biochar Amendment.

Bars are standard error of means (n=3). The same letters on the bars are not significantly different according to Tukey test at $p < 0.05$

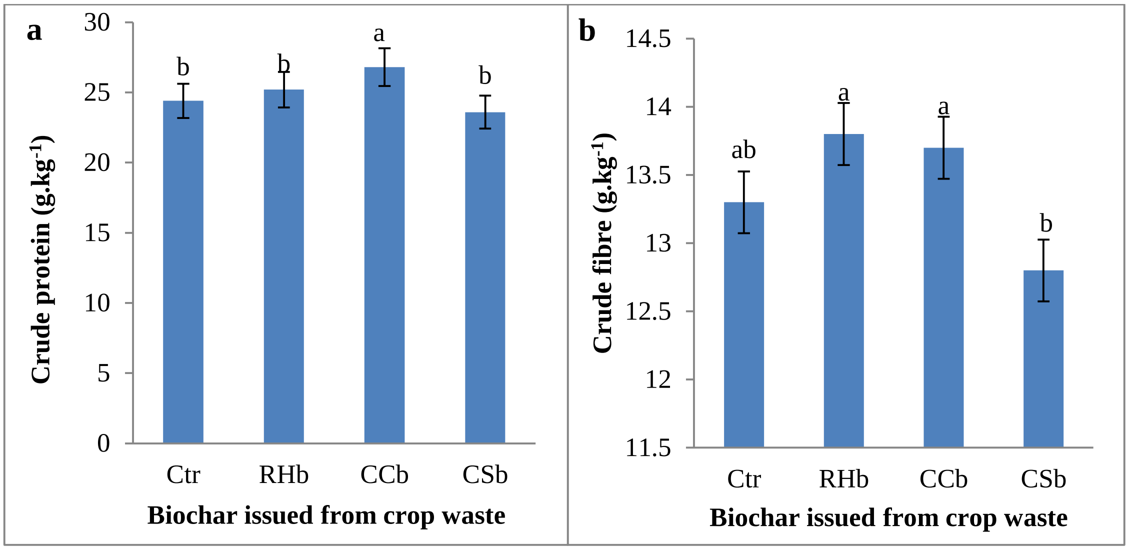

Fig.2: Influence of Biochar on (a) Crude Protein Content and (b) Crude Fibre Of Variety 8034 Cassava. Ctr: Control, CSb: Cassava biochar, RHb: Ricehusk biochar; CCb: Corncob biochar. The same letters on the bars are not significantly different according to Tukey test at $p < 0.05$

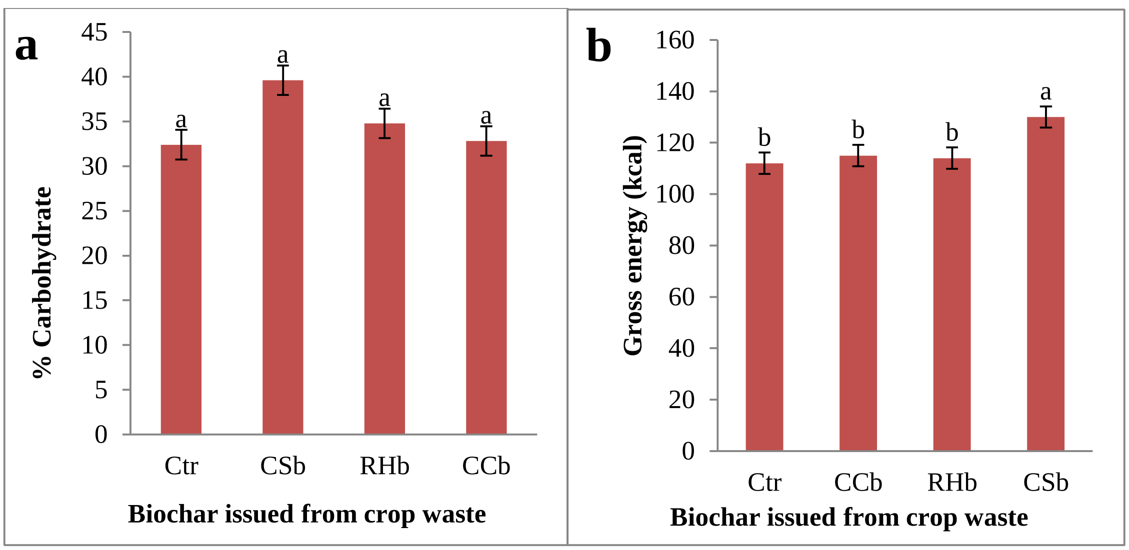

Fig.3: Influence of Biochar on (a) Carbohydrate Content (%) and (b) Gross Energy (kcal) of Variety 8034 Cassava. Ctr: Control, CSb: Cassava biochar, RHb: Ricehusk biochar; CCb: Corncob biochar. The same letters on the bars are not significantly different according to Tukey test at $p < 0.05$

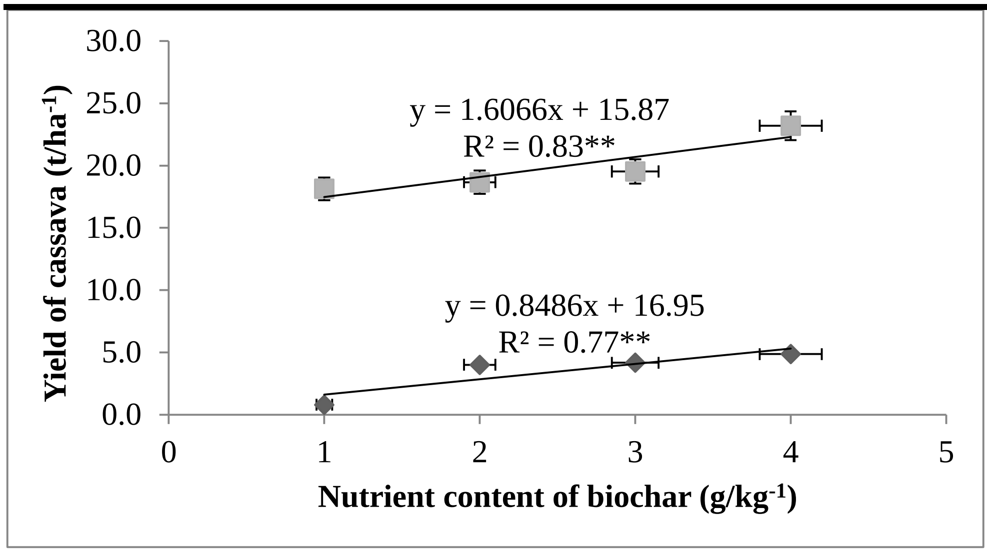

Fig.4: Relationship Between Cassava Tuber Yield and Nutrient Content of biochar