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Characterization of biochar enriched with compost tea, its effects and after-effects in continuous cultivation of maize (*Zea mays L.*) on a ferralsol of Lubuya Bera, Tshopo Province, R.D.Congo

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Abstract

The cultivation of maize, the second crop after cassava in terms of consumption in the Kisangani region, is faced with edaphic constraints aggravated by itinerant slash and burn agriculture.

Our study proposes the use of biochar enriched with compost tea to remove these constraints.

The chemical characteristics of biochar are: 2.48 to 4.68 c. moL.g-1 for the acid functions; 0.64 to 1.03 c. moL.g-1 for basic functions; 8 for the pH at the point of zero load; 64 to 103% for retention capacity; 875.3 mg.g-1 for the iodine index.

From a microbiological point of view, out of around thirty isolates, the majority of Gram-negative bacilli corresponding to the genera Nitrosomonas, Azotobacter and Nitrobacter were identified.

The experimental site was arranged according to the Device in complete random blocks with 4 blocks and 4 plots of dimensions 6 m x 4.5 m each corresponding to the following 4 treatments:

T0 (witness); T1 (Biochar over 2 mm in diameter); T2 (Biochar 2 mm in diameter); T3 (Biochar 2 mm in diameter and enriched with compost tea).

The average yields obtained increase during 8 cropping seasons under all the treatments and vary from 2.38 t.ha-1 under T0 to 7.39 t.ha-1 under T3. They are relatively higher in the dry season than in the rainy season with an average increase of around 18% and a marginal rate of return for grain maize of 4.4 under T3.

Compost tea-enriched biochar, due to its resilience, with substantial aftereffects is an important input for climate-smart agriculture.

Keywords: Biochar; Compost Tea; Climate-Smart Agriculture; Slash-and-burn agriculture

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1. Introduction

The sandy texture of the soils in the Kisangani region requires reasoned mineral fertilization combined with organic matter in order to avoid the leaching of nutrients for the crop. In the agroecological conditions of the Kisangani region, organic matter is subject to rapid mineralization due to excessive humidity and high temperatures. The regular application of mineral fertilizer to a soil rich in colloids with variable load contributes to the pollution of groundwater.

The climate-appropriate option for fertilizer application is to bury single-dose biofertilizers to improve heavily weathered and often acidic tropical soils. The application of biochar [1] due to its recalcitrance [2] to mineralization and the longevity of the residence time in the soil being measured in hundreds or even thousands of years [3, 4, 5, 6, 7, 8] has the advantage of allowing single-dose incorporation in crop fertilization with long-lasting after-effects [9] on soil properties and increased maize yields.

Biochar enriched with Compost Tea as a co-substrate [10, 11, 12, 13, 14] is proving to be the foundation of Climate-Smart Agriculture.

The present study carried out in Lubuya Bera, Province of Tshopo in the Democratic Republic of Congo, proposes to determine the fertilizing potential of Biochar enriched with compost tea under continuous cultivation of maize. It pursues three specific objectives: (i) to prepare Biochar enriched with compost tea; (ii) characterize Biochar enriched with compost tea; (iii) apply Biochar enriched to compost tea in continuous cultivation of maize.

2. Material and methods

2.1 Study area

Our study was carried out at Lubuya Bera (419 m Altitude, 00° 36' 30.6'' N, 025° 10' 13.5'' E) at kilometer point 12 on the Banalia road north of the city of Kisangani, of the Tshopo Province, in the north-eastern part of the D.R. Congo (Figure 1).

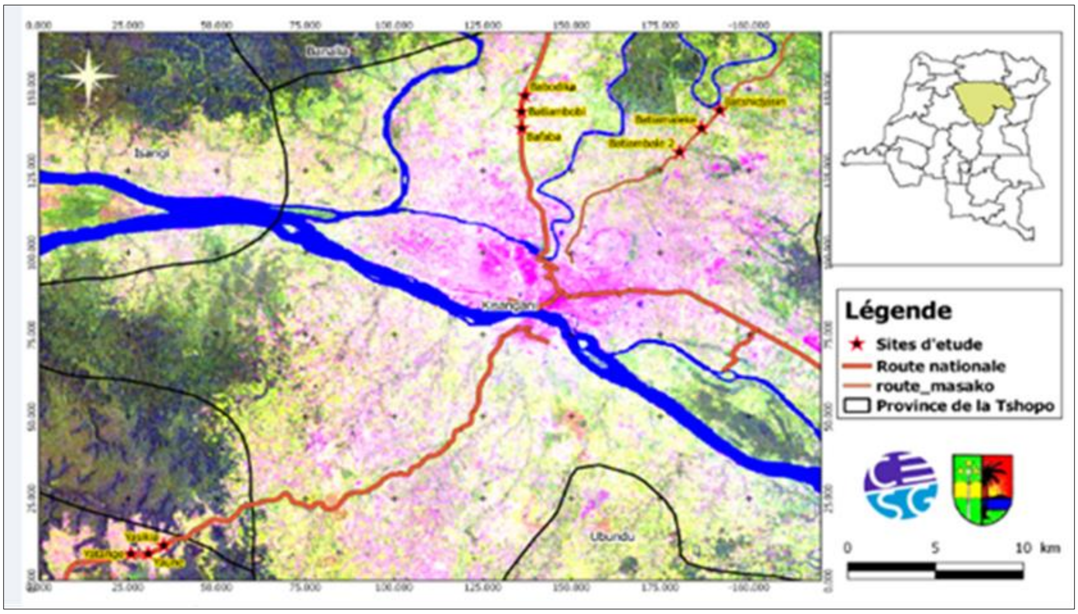

Figure 1 Map of the experimental site

2.2 Climate

The Kisangani region is characterized by the Af type climate according to the classification of [15]. The annual rainfall varies between 1600 and 1800 mm. The average temperatures at the experimental site are generally constant throughout the year plus or minus 25 °C. The highest temperatures are recorded between February and April and the lowest temperatures were obtained between the months of July and September with the monthly averages varying between 23.6°C and 24°C.

2.3 Soil

The soils of the experimental site correspond to Haplic Ferralsol (Dystric, Xanthic) according to [16]. These are soils with little textural variation with depth. According to Sys [17], the soils of Kisangani are classified in the category of those developed on more or less clayey sand accumulation surfaces and thus confirm their fluvio-lacustrine origin attributed to the Yangambi series.

2.4 Vegetation

During the development of the experimental site, the following grassy fallow species were inventoried: *Chromolaena odorata*, *Imperata cylindrica*, *Spermacoce latifolia*, *Cynodon dactylon*.

2.5 Materials

The plant material consisted of maize seeds (*Zea mays L*. var QPM blanc), common bamboo (*Bambusa vulgaris*) while the non-biological materials concerned chemical reagents and microbiological products.

2.6 Methods

For conditioning the biochar, we used moderate pyrolysis of dry common bamboo (*Bambusa vulgaris*) mixed with wet bamboo characterized by a temperature of around 500°C for 5 days. The coal thus obtained was crushed and sieved on the granulometric grid of 2 mm in diameter. The resulting powder was soaked to saturation for 24 hours with sodium hypochlorite (NaClO) solution diluted 4 times for chemical activation.

It was a question of increasing the adsorbent power of the biochar, in particular by eliminating the tars which clog the pores. The wort obtained was then dried in a muffle oven at a temperature of 800°C for 20 minutes. The resulting powder was washed several times and air dried.

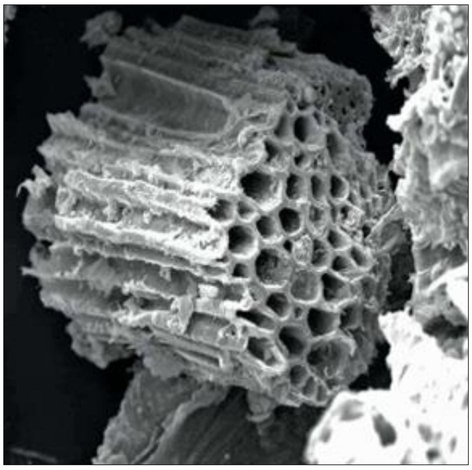

Figure 2 Microscopic view of bamboo biochar [18]

The biochar obtained was enriched by saturation for 24 hours with the compost tea solution rich in microorganisms. Obtaining compost tea consisted of mixing raw compost and water (in a ratio of 1/10, weight/volume) in a fermenter under oxygen bubbling for 8 hours in order to boost the multiplication of microorganisms.

The determination of the pH at which the electric charge of Biochar is zero (pHpzc) was carried out according to the modified Boehm titration [19]. The determination of the acid functions (carboxylic acids, phenols and lactones) and basic functions (primary amines, secondary amines and protonable tertiary amines) of the biochar was carried out according to Boehm [20].

Regarding the adsorption capacity, we determined by titrimetry the iodine number. The iodine value is the amount in milligrams of iodine adsorbed per gram of biochar in an iodine solution. It characterizes the zones accessible to particles of a size greater than or equal to that of the iodine molecule, in particular the micropores.

At flowering, soil samples were taken from each plot at flowering to determine edaphic and microbiological parameters. The vegetative parameters measured are the height of the plants and the diameter at the collar. At harvest, the following generative parameters: weight of ears, length of ears, diameter of ears, number of rows of maize were determined.

The pH of the water was measured by the electrometric method in a soil:water ratio of 1:2.5. The particle size analysis was determined by the pipette method; total organic carbon by wet process according to Valkey and Black [21], total nitrogen according to Kjedhal [22] after mineralization and assimilable phosphorus according to Olsen [23]. Acid cations (H+ and Al3+) were determined after extraction with AG – TU reagent according to [24] by titrimetry and exchangeable bases (Ca, Mg, K, Na) by atomic absorption spectrometry.

With regard to the microbiological analyses, the soil samples at a rate of 2 g were taken at the level of the rhizosphere of the culture, at a depth of 15 cm. For the isolation of bacteria, we used 5 types of culture medium: (i) soil-based medium; (ii) nitrite broth; (iii) ammonium broth; (iv) medium based on mineral elements; (v) nutrient agar + ammonium; nutrient agar + nitrite; nutrient agar + nitrate.

For the isolation of bacteria, we prepared 4 types of culture medium: (i) soil-based medium; (ii) nitrite broth; (iii) ammonium broth; (iv) medium based on mineral elements; (v) nutrient agar + ammonium; nutrient agar + nitrite; nutrient agar + nitrate.

For the purification of isolated bacteria, we used 3 media, namely: (i) nutrient broth + Agar + $(NH_4)_2SO_4$; (ii) nutrient broth + Agar + $NaNO_2$; (iii) nutrient broth + Agar + KNO_3 to promote the growth of nitrifying bacteria.

Ten typical colonies are isolated from each sample from the Petri dishes containing the medium and subcultured in the nitritive broth and incubated at 30°C. For Gram staining, the procedure is that of [25, 26].

The macroscopic identification elements are: (i) the shape of the colonies: round, irregular; (ii) the size of the colonies by measuring the diameter: pinctiform or non-pinctiform; (iii) chromogenesis: color of the colony; elevation: convex, concave, flat; (iv) opacity: opaque, translucent or transparent; (v) surface: smooth, rough, dry, jagged, etc.

The fermentation type test makes it possible to know the type of metabolism by which the substrate is transformed, and the production of gas from the reduction or oxidation of ammonia, nitrite and nitrate.

2.7 Experimental design

After land clearing and stump removal, plowing was done with a hoe to a depth of about 30 cm.

The land was arranged according to the Device in complete randomized blocks (figure 7) with 4 blocks and 4 plots of dimensions 6 m x 4.5 m each corresponding to the following 4 randomized treatments:

- T_0 : Control
- T_1 : Biochar greater than 2 mm in diameter
- T_2 : Biochar 2 mm in diameter
- T_3 : Biochar 2 mm in diameter and enriched with compost tea

Our test was carried out continuously after burying the single dose of biochar from 2020 to 2022 for 8 cropping seasons, from July 13, 2020 to October 20, 2020 (rainy season); from November 01, 2020 to February 15, 2021 (dry season) and from March 06, 2021 to June 22, 2021 (rainy season); from July 04, 2021 to October 01, 2021 (dry season); from October 19, 2021 to January 12, 2022 (rainy season); from January 27, 2021 to April 10, 2022 (dry season); from April 24, 2022 to July 17, 2022 (rainy season); from July 29, 2022 to October 11, 2022 (dry season). The aim is to assess the effects and after-effects of the treatments applied.

We then proceeded to sow the maize at spacings of 0.75 m x 0.25 m at the rate of 2 seeds per pocket. The refilling of voids took place one week after sowing while the weeding, thinning and ridging were carried out three weeks after emergence. After each harvest, the stems, leaves, husks and stalks of each plot are spread on the surface to serve as a substrate for the enzymes of the soil microorganisms. This system was followed by direct seeding for the following season.

The grain yield determined, the economic profitability of the trial was evaluated according to [27]. The overall cost of the trial concerns the labor for (i) the cultivation operations; (ii) the conditioning of the biochar and the constitution of the composter and (iii) the price of the seeds at the rate of US$ 0.75 per kilogram.

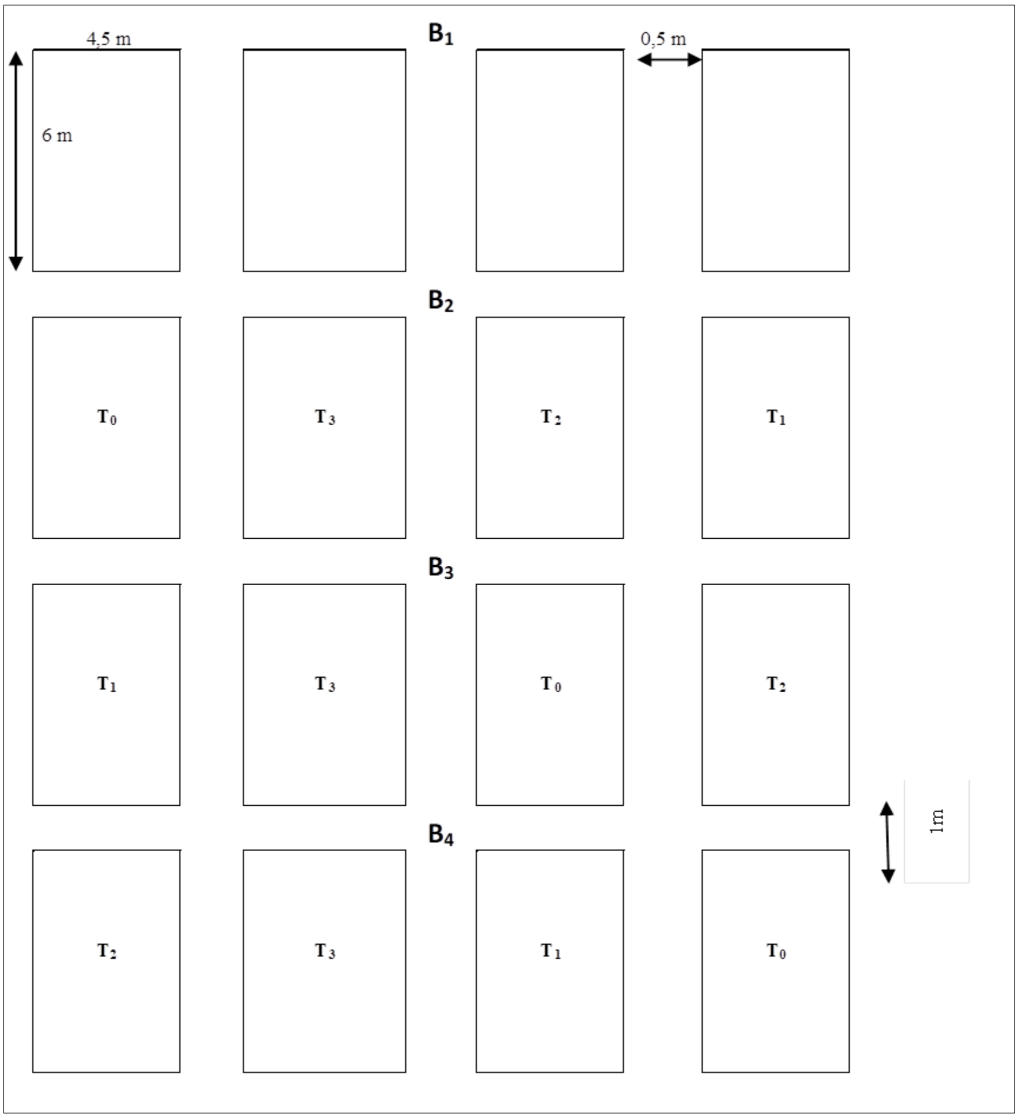

Figure 3 Experimental device of the assay

The statistical analyzes performed according to [28, 29] were computer-assisted using Microstat, Irristat and Slan software.

3. Results

3.1 Chemical analysis of biochar

The zero charge point pH (pHpzc) is 8 whereas the ferrallitic soils of Kisangani are often found near the isoelectric point at pH 4.5 [30]. The biochar is thus revealed as a basic amendment with a high buffering power, capable of solubilizing the phosphorus fixed by the acid ions of the Ferralsols.

The biochars show interesting surface functions (tabl.1) due to the presence of acidic and basic functional groups. The latter resulting from pyrolysis fight on the one hand against the acidity of the soil [31, 32] by protonation of organic anions [11, 12, 13] and chelation of toxic ions such as exchangeable aluminum (Al^{3+}) and on the other hand increase the buffering capacity of soils rich in mineral colloids with variable charge.

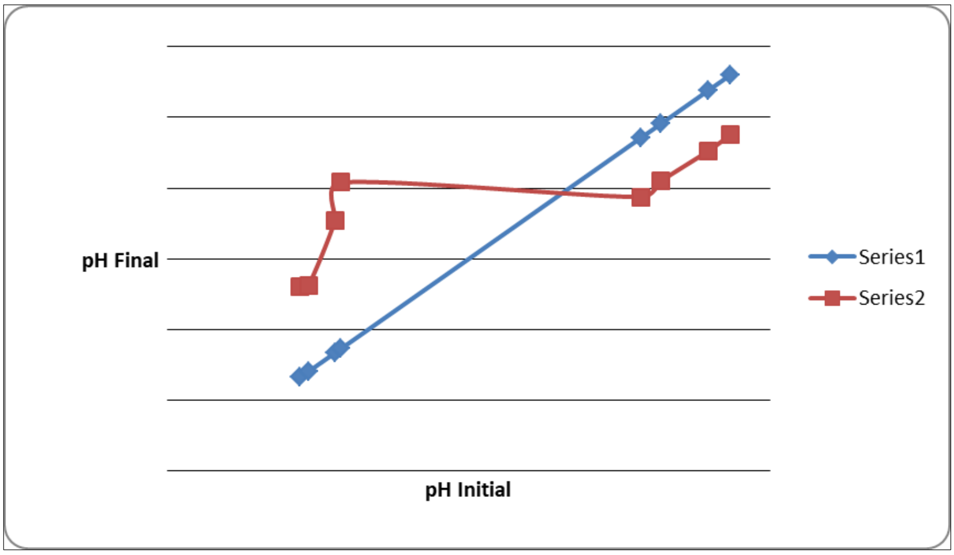

Figure 4 Determination of pHPZC of Compost Tea Enriched Biochar

The predominance of acidic functional groups acting as electron acceptors are hydrophilic [7] and increase the retention capacity of biogenic elements. The high iodine number reflects the adsorption potential of the micropores. The biochar enriched with compost tea shows an increase of about 61%, 89% and 61% respectively for the retention capacity, the acid functions and the basic functions compared to the dry biochar. The high iodine number of 875.3 mg.g^{-1} is an index of micropore occupancy by compost tea microorganisms.

Table no. 1 Surface chemical characteristics of biochars

	Biochar	**Biochar enrichi**
Total acid functions (meq.g-1)	2.48	4.68
Carboxyl (-COOH)	0.86	1.55
Lactones (- C00-)	0.9	1.78
Phénol (- OH)	0.72	1.35
Total basic functions (meq.g-1)	0.64	1.03
(Amines, - NH2)	0.64	1.03
pHPZC	8.01	8.0
CRE (%)	165.8	222.7
II (mg.g-1)	875.3	

Legend.; pHpzc: zero charge point pH; CRE: Retention capacity; II: Iodine Index

3.2 Microbiological analysis

The community of microorganisms (tabl.2, 3) in Biochar is dominated by ammonifying and nitrifying bacteria. The essential character of the microbiological analysis of the soil being ecological, the improvement of the reaction of the soil favors the transformation of molecular nitrogen into nitrates whose mobility is reduced by the acid functions of Biochar enriched with compost tea.

The supply of carbon by biochar and soil bacteria play an essential role in pedogenesis through the formation of stable aggregates resulting in a lumpy structure, a key factor for climate-smart agriculture.

Table 2 Bacterial characterization of compost tea-enriched biochar

Treatment	Broth based on NH_4^+		Broth based on NO_2^-		Broth based on NO_3^-	
	NH_4^+	NO_2^-	NH_4^+	NO_2^-	NH_4^+	NO_2^-
T_0	Small Rod - shaped bacteria	Small Rod – shaped bacteria and chain – shaped bacteria	Rod – shaped bactéria	Small Rod – shaped bacteria and chain – shaped bacteria	Rod – shaped bactéria	Small Rod - shaped bacteria
T_1	Small Rod – shaped bacteria and chain – shaped bacteria	Small Rod – shaped bacteria and chain – shaped bacteria	Rod – shaped bactéria	Rod – shaped bactéria	Small Rod - shaped bacteria	Small Rod – shaped bacteria
T_2	Small Rod – shaped bacteria and chain – shaped bacteria	Small Rod - shaped bacteria	Small Rod – shaped and rounded bacteria	Small Rod - shaped bacteria	bacteria in the shape of a small rod, rounded and pointed	Small Rod – shaped and rounded bacteria
T_3	Small Rod – shaped and rounded bacteria	Small Rod - shaped bacteria	Small Rod – shaped and rounded bacteria	Small Rod - shaped bacteria	Small Rod – shaped and rounded bacteria	Small Rod – shaped and rounded bacteria

3.3 Soil parameters

The allitization of clay minerals in a strongly drained environment such as the Kisangani region requires argillogenesis by neoformation thanks to the contribution of organic matter rich in lignin (24.3% of organic carbon under T_3) and in water-soluble compounds (2.4 % total nitrogen under T_3) for the promotion of humification to the detriment of mineralization.

The high cation exchange capacity (44.66 $c.mol^+kg^{-1}$) due to the contribution of the biochar enriched in the compost tea contributes to the improvement of the physical properties of the soil and thus to the economy of the soil. soil water in the context of climate change.

Acidity and aluminum toxicity are among the major soil constraints in maize production. Biochar enriched with compost tea reduced the levels of exchangeable aluminum by 19%, thus reducing the saturation rate of the adsorbent complex with exchangeable aluminum to 20%, a rate favorable for optimal corn growth. In our agro-ecological zone, the high acidity (pH = 4.6) of the soils (table 4) constitutes the major edaphic constraint for increasing maize yields, which is very sensitive to the aluminum and manganese toxicity of acid soils. The biochar enriched with compost tea with a pHpzc of 8 fights against the acid factors, responsible for aluminum toxicity, solubilises the retrograded phosphorus and if necessary contributes to the increase in yield (tabl 5) of 1954% compared to the control.

Table 3 Soil parameters under different treatments

Traitements	T_0	T_1	T_2	T_3
pH	4.6	7.6	8.1	9.3
Org C (%)	0.725	21.6	24.3	24.3
Total N (%)	0.062	0.8	0.8	2.4
C/N	11.7	27.0	30.4	10.1
Ass P (mg. kg^{-1})	8.02	22.33	44.6	115.0
Exch Ca (c.mol $^{+}kg^{-1}$)	0.78	6.8	8.53	9.68
Exch Mg (c.mol $^{+}kg^{-1}$)	0.13	0.75	2.1	3.66
Exch K (c.mol $^{+}kg^{-1}$)	0.18	12.3	14.5	15.22
Exch Na (c.mol $^{+}kg^{-1}$)	0.05	1.57	1.61	2.08
Exch H (c.mol $^{+}kg^{-1}$)	0.75	0.69	0.41	0.14
Exch Al (c.mol $^{+}kg^{-1}$)	0.68	0.61	0.15	0.13
CEC (c.mol $^{+}kg^{-1}$)	4.9	26.9	31.5	44.66
Sand (%)	63.0	64.0	66.0	70.0
Silt (%)	27.0	24.0	22.0	24.0
Clay (%)	10.0	12.0	12.0	6.0
Texture (FAO)	LS	LS	LS	LS

Legend. Org C : Organic Carbon ; Total N : Total Nitrogen ; Ass P : Assimilable Phosphorus ;Exch Ca : Exchangeable Calcium ; Exch Mg : Exchangeable Magnesium ; Exch K : Exchangeable Potassium ;Exch Na : Exchangeable Sodium ; Exch H : Exchangeable Hydrogène ; Exch Al :Exchangeable Aluminium ; CEC : Cation Exchange Capacity ; LS : Limon Sable

3.4 Yied

The combined effects of pH correction and the chelation of acid ions by the organic matter of biochar enriched with compost tea make it possible to sustainably grow maize continuously on acidic Ferralsols. In the first growing season, biochar enriched with compost tea induces a 148% increase in corn yield compared to the control. Table 6 shows that the weight of maize seeds is significantly influenced ($r = 0.73$) at the 1% level by the diameter of the cob, a parameter inherent in genetics. Due to the recalcitrance of biochar combined with compost tea, we believe that production will increase significantly ($p < 0.05$) over time by around 210%. This is the resilience of maize cultivation in the face of climate change. Significant yield increases over the control.

Table 4 Effect of treatments on grain corn yield components in cultivation

Treatments	Weight(g) Epis	Length (cm) Epis	Diameter (cm) Epis	Number of Rows	Weight (g) grains	Grain Yield t/ha)
T_0	74.07^a	11.11^a	12.33^a	14^a	4320^a	1.,6^a
T_1	80.04^b	11.53^a	12.64^b	14^a	5616^b	2.08^b
T_2	80.5^b	11.57^a	12.76^b	14^a	6210^c	2.3^c
T_3	85.16^c	11.73^a	13.01^c	14^a	6426^d	2.38^d

The different letters next to the means indicate significant difference, and the same letters indicate non-significant differences after comparison of the means by Pearson's test (P=0.05).

With respect to the length of the ears and the number of rows, the treatments have no significant effects at the 5% threshold. The difference is rather observed in the diameter of the cobs, the average of which (12.685 cm) for all treatments combined exceeds by 207% that (4.128 cm) found by [33].

The length of ears under T3, biochar enriched with compost tea 11.73 exceeds that found by [34], i.e. 10.6 under decomposing cotton hulls mixed with urea in maize cultivation.

Unlike traditional agriculture where the continuous cultivation of maize is characterized by a sharp drop in yield over time, the after effects of biochar enriched with compost tea are expressed by significant increases in yields over time. The continuous improvement of the colloidal properties of this amendment is responsible for these performance after effects.

Table 5 After Effect of treatments on grain maize yield variation in continuous cropping

Année	T_0 ($t.ha^{-1}$)	T_1 ($t.ha^{-1}$)	T_2 ($t.ha^{-1}$)	T_3 ($t.ha^{-1}$)
2020 (RS)	1.6[a]	2.08[a]	2.3[a]	2.38[a]
2021 (DS)	1.37[a]	2.59[b]	3.59[c]	4.07[c]
2021 (RS)	1.53[a]	2.63[b]	3.66[c]	5.03[d]
2021 (DS)	0.87[a]	2.23[b]	3.60[c]	5.52[d]
2021 (RS)	0.75[a]	2.67[b]	4.93[c]	5.61[c]
2022 (DS)	0.71[a]	2.50[b]	4.95[c]	6.44[d]
2022 (RS)	0.58[a]	2.98[b]	5.02[c]	6.84[d]
2022 (DS)	0.35[a]	2.40[b]	4.97[c]	7.39[d]
Moyenne	**0.97[a]**	**2.51[b]**	**4.13[c]**	**5.40[d]**

RS: Rainy Season; DS: Dry Season.

Over time, the grain maize yield varied according to the treatments with significant differences ($p < 0.05$). The control, T_0, suffered a decrease in yield of around 78% against a significant increase (210%) under T_3, the biochar enriched with compost tea. In addition, for the same year, we observe an increase in grain yield in the dry season compared to the rainy season. The crop benefiting from maximum light in the dry season on the one hand and from a water and mineral reserve ensured by the biochar enriched with compost tea on the other hand transpires efficiently and develops more dry matter. The rear effects of the treatments on grain maize yields are respectively 0.97 $t.ha^{-1}$; 2.51 $t.ha^{-1}$; 4.13 $t.ha^{-1}$ and 5.40 $t.ha^{-1}$ respectively under T_0, T_1, T_2 and T_3.

3.5 Financial profitability

Table 6 Effects of different treatments on the financial profitability of grain maize in the eighth cropping season

	T_0	T_1	T_2	T_3
Total Cost (US$)	1790.0	2040.0	2205.0	2231.0
Marginal Cost (US$)	-	250.0	415.0	541.0
Yield ($t.\ ha^{-1}$)	0.35	2.40	4.97	6.84
Δ Yield ($t.\ ha^{-1}$)	-	2.05	4.62	6.49
Value Δ Yield (US$)	-	720.0	1372.5	2490.0
Ratio Value/Cost (RVC)	-	2.9	3.3	4.6

Légend. Δ Yield (t. ha-1) : Yield Increase in tons per hectare

A treatment is considered profitable in agriculture when the level of return on the investment is at least twice the cost of the investment, i.e. when the Value/Cost ratio of the investment is greater than 2 [35].

For our test, the economic returns (table 7) of the production of grain maize under T_1, T_2 and T_3 are respectively 2.9; 3.3 and 4.6 demonstrate that our treatments are cost effective. Improving the financial profitability of maize cultivation could contribute to the mechanization of operations for the production of biochar enriched with compost tea, harvesting and post-harvest of maize.

4. Discussion

4.1 Chemical characterization of biochar

The acid functions (AF) adsorbed on the ML biochar is 2.48 meq.g^{-1} and exceed or nearly 225% while the acid functions of the phragmite-based biochar is 0.0074 meq.g^{-1} and nearly 85% for biochar based on seaweed [36]. The ratio FB biochar bamboo/FB biochar phragmites is 98 and 2.17 for the FB of bamboo biochar/FB biochar seaweed described by [37]. This ratio is higher than that recorded for regular biochar and biochar enriched with compost tea which is 0.64 and 1.03.

The pH at zero charge, pHpzc is the pH at which the electrical charge of the biochar is zero, for the biochars under study it is 8 i.e. alkaline. This allows the adsorption of biogenic elements and the correction of soil reaction. While the Phragmites-based biochar revealed an average pH of 6.95 [36] compared to 4.25 for the Sargassum vulgare biochar [37], these values are lower than those recorded during this study.

In acidic soil conditions, the adsorption of anions including phosphates and nitrates on the biochar is favored at pH values below the pHpzc [38]. Acid ions, notably Al^{3+}, will form mobile chelates and undergo leaching.

[39] ont trouvé un indice d'iode de 190.21 mg. g^{-1} pour la paille de riz contre 846 mg. g^{-1} pour l'algue marine chez [36] ; alors que [40] ont testé la bentonite algérienne ($Qmax$ = 118 mg·g^{-1}) avec un temps de contact de 3 h. [37] ont trouvé un indice d'iode moyen de 457.2 mg. g^{-1} pour le *Phragmites*.

The iodine number test indicates an increase in the specific surface when increasing the impregnation ratio. This is due to the development of microporosity. The iodine value gives information on the surfaces of the micropores (internal surfaces) accessible to small molecules and metals.

[39] found an iodine number of 190.21 mg. g^{-1} for rice straw against 846 mg. g^{-1} for seaweed in [36]; whereas [40] tested Algerian bentonite (Qmax = 118 mg·g^{-1}) with a contact time of 3 h. [37] found an average iodine value of 457.2 mg. g^{-1} for Phragmites.

We can affirm that our bamboo-based biochar with an iodine number of 875.30 mg.g^{-1} (tabl. 10) has larger micropore surfaces. This can promote soil water saving and build resilience to climate change in the context of predominant rain-fed agriculture in Africa. These micropores can serve as prime habitats for potent, biofertilizing microorganisms.

4.2 Bacterial characterization of Biochar enriched with compost tea

From different samples, ten colonies were observed showing morphological resemblance to the genus *Nitrobacter* according to Bergey's manual of determinative bacteriology.

The results obtained during the microscopic observation in the soil-based medium revealed to us that our samples contained mostly species of Gram-negative bacteria and in the form of bacillus. These results are consistent with the work carried out by [41] who characterized the cultures enriched with nitrifying bacteria from the black cotton soil of the cougar basin showing a resemblance of its isolates to the genera *Nitrobacter* and *Nitromonas* which were Gram negative.

After identification of isolates based on morphological characteristics; On about thirty isolates (table 2), the majority of isolates being bacilli, in the shape of a point or rounded corresponding to the genus *Nitrosomonas* and *Azotobacter* (T_1, T_2 and T_3) and *Nitrobacter* (T_1, T_2) They were Gram negative and a few isolates in the chain were Gram positive.

Contrary to Degrange [42], despite the unfavorable physicochemical characteristics of the environment (acid pH), we noticed the preponderance of the genus *Nitrobacter* which, in the absence of nitrite (NO_2^-), oxidizes the ammonium ion (NH_4^+) to nitrate (NO_3^-) which is the form of nitrogen taken up by the crop but not available in our condition due to leaching.

The presence of the genera *Azotobacter* and *Nitrosomonas* in the pots under biochar enriched with compost tea reflects the reducing and oxidizing activity of these microorganisms in the nitrogen cycle. The reduction of atmospheric nitrogen, N_2 to ammonium ion (NH_4^+) by *Azotobacter* is followed by the reduction of the latter adsorbed to nitrate (NO_3^-) as described by [43]. Nitrate which is available for culture in a basic medium regulated by the contribution of biochar enriched with compost tea whose pH at zero load, pHpzc is 8.

Our results are close to those obtained by [44]; who isolated and characterized developmental promoter bacteria (PGPB) associated with chickpea (*Cicer arietinum L.*). These results show that the selected nitrogen-fixing isolates (Nf5, NfA, NfC, and NfD) are Gram-negative, motile, strict aerobic, and somewhat rounded bacilli. These isolates have a positive reaction to catalase and oxidase: phenotypic observation and biochemical identification of the selected nitrogen-fixing isolates (Nf5, NfA, NfC and NfD) showed their belonging to the genus *Azotobacter* and *Nitrobacter* [45].

4.3 Yield: After effects

The world average maize yield is 4.32 t. ha^{-1} against 1.56 t. ha^{-1} for the African continent and 0.82 t. ha^{-1} for the D.R. Congo [46]. The yield of our test varying between 4.07 to 7.39 t. ha^{-1} exceeds that of [47] which, using mineral fertilizers, obtains 3.7 t. ha^{-1} with arbuscular mycorrhizal fungi against 6.1 t. ha^{-1} for 60 kg of P_2O_5 and 5 t. ha^{-1} for the combination of arbuscular mycorrhizal fungi and 60 kg of P_2O_5. [48] found, all treatments combined, yields of around 3.9 t. ha^{-1}. Our trial with an average yield of 5.4 t.ha^{-1} all seasons combined is part of a resilient agriculture, the after effects of biochar enriched with compost tea can generate higher yields.

4.4 Financial profitability

Our value-to-cost ratios (VCR) of 2.9; 3.3 and 4.6 under T_1, T_2 and T_3 are respective net profits of 470.0 US$; 957, 5 US$ and 1,949 US$ for an area of 1 hectare exceed those found by Useni [49] and [50] with respective average returns of 2.42 and 0.84. Our values of the benefit-cost ratio are higher than that of [51] with an RVC of 1.27 under mineral fertilizer for maize production in Ouaké in North-West Benin. The RVC under compost tea enriched biochar (4.6) exceeds that of [52] with a ratio of 3.29 in maize cultivation in Adamawa state in Nigeria.

The ratios of [53] and [54] respectively of 6.11 in Nigeria, 45.21 in Ethiopia with mineral manure under an irrigated system and 85.11 with the maize and soybean association largely exceed our ratio of 4.6.

The use of adapted cultivation techniques (association and rotation) could further optimize the financial and ecological profitability of maize in the edapho-climatic conditions of Lubuya Bera.

Indeed, [55] found that in the United States of America, 40% increase in maize yield is attributable to improved cultivation practices.

5. Conclusion

Surface chemical characteristics (FA = 4.68 meq.g^{-1}; FB = 1.03 meq.g^{-1}; pHpzc = 8; CRE = 222.7%; II = 875.3 mg.g^{-1}) give biochar enriched with compost tea interesting colloidal properties as a regulator of soil reaction, adsorbing organic anions including assimilable phosphorus (15.1 mg. kg^{-1}), chelating agent for toxic acid cations and ecological niche (II = 875.3 mg.g^{-1}) by these micropores to Gram-negative bacteria corresponding to the genera Nitrosomonas, Azotobacter and Nitrobacter, molecular nitrogen-fixing bacteria.

The porous structure, the high specific surface highlighted by the iodine index of 875.30 mg.g^{-1} is likely to increase the affinity of the biochar for charged particles and soil water thus contributing to resilience in a context of climate change.

The effects and after-effects of biochar enriched with compost tea induce increases in grain maize yield of around 210% compared to the control. The adsorption of water and nutrients on the one hand and the presence of microorganisms in the pores of the biochar on the other hand will generate ever-increasing yields over time in the context of climate-smart agriculture.

The RVC of a value greater than 2 suggests the investment in the production of compost tea-enriched biochar buried once and in a single dose in the soil.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest in respect to this article.

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