International Journal of Scientific Research Updates

Journal homepage: https://orionjournals.com/ijsru/

ISSN: 2783-0160 (Online)

ORION SCHOLAR JOURNALS

(RESEARCH ARTICLE)

Check for updates

Response of two varieties of okra (*Abelmoschus esculentus L. Moench*) to the application of biochar enriched with compost tea in urban

Adrien MOANGO MANGA [1,*], Achille Monzongo Linzembe [2], Marie Claire Yandju Dembo [3], Mavinga Blaise MBALA [3], Léon Kasaka Dingbo [4] and Hubert Katapulu Kunda [5]

[1] *Faculty of Sciences, University of Kisangani; Democratic Republic of Congo.*
[2] *Faculty of Agricultural Sciences, University of Ikela; Democratic Republic of Congo.*
[3] *Faculty of Sciences, University of Kinshasa; Democratic Republic of Congo.*
[4] *Faculty of Management of Renewable Natural Resources, University of Kisangani; Democratic Republic of Congo.*
[5] *Faculty of Applied Sciences, Catholic University of Kisangani; Democratic Republic of Congo.*

International Journal of Scientific Research Updates, 2023, 05(01), 055–066

Publication history: Received on 01December 2022; revised on 12 January 2023; accepted on 15 January 2023

Article DOI: https://doi.org/10.53430/ijsru.2023.5.1.0002

Abstract

The poor management of soil fertility is the major edaphic constraint in the production of Okra, a vegetable highly appreciated by consumers in Kisangani.

The objective of our study is to test the different combinations of organic manure in order to determine the most efficient ones on the yield of two varieties of okra in urban agriculture in Kisangani. Okra cultivation is seen as a climate-resilient and income-generating activity.

The different treatments are determined in relation to the varieties studied. For the Indiana variety: T0, T1, T2 and T3 represent the control, the biochar, the compost tea and the biochar*compost tea combination respectively. The same treatments apply to the Clemson spineless variety. The experimental device adopted is that of split plot with 3 repetitions.

The response of the test plant to the treatments applied was assessed on all the plants except the border plants. The results of the experimental treatments, the relationships between the biological parameters of different populations were respectively compared and determined.

Yields vary by variety and treatment. Yields of the Indiana variety are 47.4 t.ha-1 under biochar associated with compost tea against 33.8 t.ha-1 under Clemson spineless. The marginal rate of return for the Indiana variety is 4.4 under the biochar*compost tea combination versus 2.1 for the Clemson spineless variety. Biochar combined with compost tea is proving successful in urban okra farming in Kisangani.

Keywords: Charcoal; Compost tea; *Abelmoschus esculentus L. Moench*; Indiana; Clemsen spineless

1. Introduction

Tropical pedogenesis is characterized by total hydrolysis responsible for several edaphic constraints including soil acidity. Indeed, the aggressiveness of the climate in a drained environment causes the leaching of bivalent elements [1,2] causing soil acidity with considerable negative training effects such as the retrogradation of phosphorus. In this context, the effectiveness of the application of mineral fertilizers is really mixed.

*Corresponding author: Adrien MOANGO MANGA.

Also for sustainable management of soil fertility, innovation consists in using simple, less expensive, ecologically sound, resilient and profitable techniques. These include the synergy of compost tea and biochar, a lever in the fight against soil acidity and aluminum toxicity and, where applicable, the availability of phosphorus [3] in the ferralsols of the Kisangani region.

Indeed, due to its resilience [4, 5, 6, 7], biochar applied to the soil contributes to limiting the leaching of nutrients and, if necessary, to reducing mineral fertilization [8, 9]. Compost tea characterized by its richness in microbial biodiversity is revealed as an adjuvant to biochar by providing nitrogen, phosphorus and potassium to crops. Indeed, microorganisms play an essential role in pedogenesis through the formation of stable aggregates generating a lumpy structure, a key factor for climate-smart agriculture. Biochar, due to its porosity, constitutes a privileged habitat for soil microorganisms [10]. The Biochar*Compost Tea synergy can sustainably improve soil properties [11, 12] and allow sedentarization of agriculture. The results of this study may help small farmers to sedentarize agriculture. Achieving this objective requires the following specific objectives: (i) improve the properties of ferralitic soils using biochar enriched with compost tea; (ii) increase the yield of okra in ferrallitic soils by biochar enriched with compost tea.

Tropical pedogenesis is characterized by total hydrolysis responsible for several edaphic constraints including soil acidity. Indeed, the aggressiveness of the climate in a drained environment causes the leaching of bivalent elements [1,2] causing soil acidity with considerable negative training effects such as the retrogradation of phosphorus.

Indeed, due to its resilience [4, 5, 6, 7], biochar applied to the soil contributes to limiting the leaching of nutrients and, if necessary, to reducing mineral fertilization [8, 9]. Compost tea characterized by its richness in microbial biodiversity is revealed as an adjuvant to biochar by providing nitrogen, phosphorus and potassium to crops. Indeed, microorganisms play an essential role in pedogenesis through the formation of stable aggregates generating a lumpy structure, a key factor for climate-smart agriculture. Biochar, due to its porosity, constitutes a privileged habitat for soil microorganisms [10]. The Biochar*Compost Tea synergy can sustainably improve soil properties [11, 12] and allow sedentarization of agriculture. The results of this study may help small farmers to sedentarize agriculture. Achieving this objective requires the following specific objectives: (i) improve the properties of ferralitic soils using biochar enriched with compost tea; (ii) increase the yield of okra in ferrallitic soils by biochar enriched with compost tea.

2. Material and methods

The test was carried out within the premises of the Faculty of Sciences in the Commune MAKISO, City of Kisangani. The geographic coordinates of the experimental site are as follows: 405 m altitude, 00°30' 41.5'' North latitude, 025°12' 30.2'' East longitude. Our trial took place over 3 months and 25 days from May 03 to August 28, 2021.

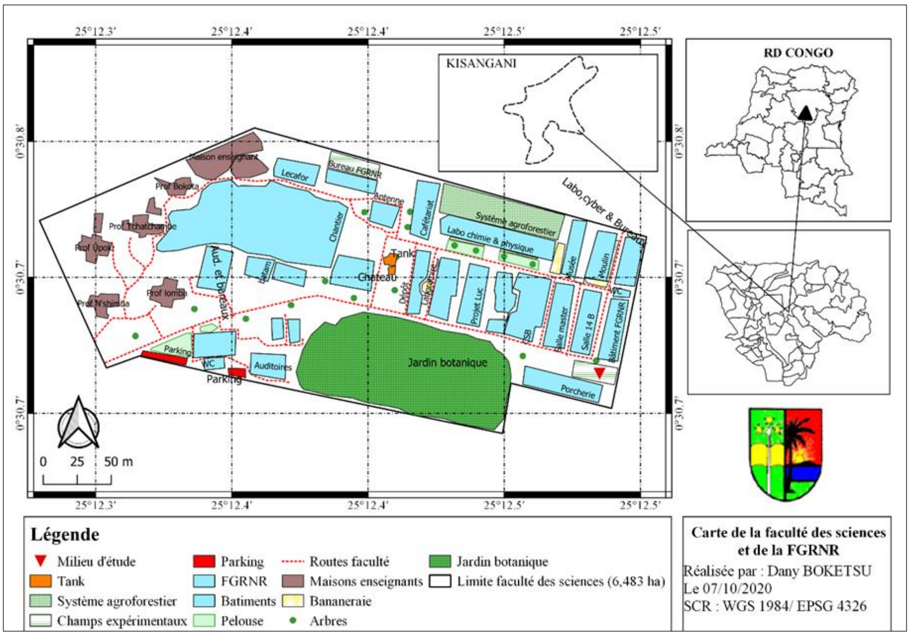


Figure 1 Experimental site

2.1 Climate

According to the Köppen classification, Kisangani belongs to the Af climatic type. Precipitation and temperatures that prevailed during the experimental period are recorded in Table 1.

Table 1 Temperatures and precipitation during the experimental period

Month	Maximum Temperature in °C	Minimum Temperature in °C	Average Temperature in °C	Rainfall in mm	Number of rainy days
May	37.6	18.7	25.0	90.8	17.0
June	33.0	18.8	24.4	25.2	10.0
July	29.9	20.1	24.1	90.7	9.0
August	30.2	20.3	24.2	90.5	8.0

Source: Meteorological Service (Bangboka airport), 2021

2.2 Soil

In general, the soils of Kisangani are extremely acidic (pH around 4.5), with a sandy texture, low in organic matter. This type of soil corresponds to Haplic Ferralsol (Dystric, Xanthic) according to WRB [13].

Vegetation

During the development of the experimental site, the following species were observed: *Panicum maximum*, *Panicum ripens*, *Chloris phyllo,Hewitia sublobata*, *Cynodon dactylon*, *Cyperus esculentus*, *Pueraria javanica*. The previous crop was the combination of amaranths and tomatoes.

2.3 Materials and Methods

Two varieties of Okra were the subject of our study: Indiana variety with elongated green fruits (V_1) and Clemson spineless variety with rounded green fruits (V_2).

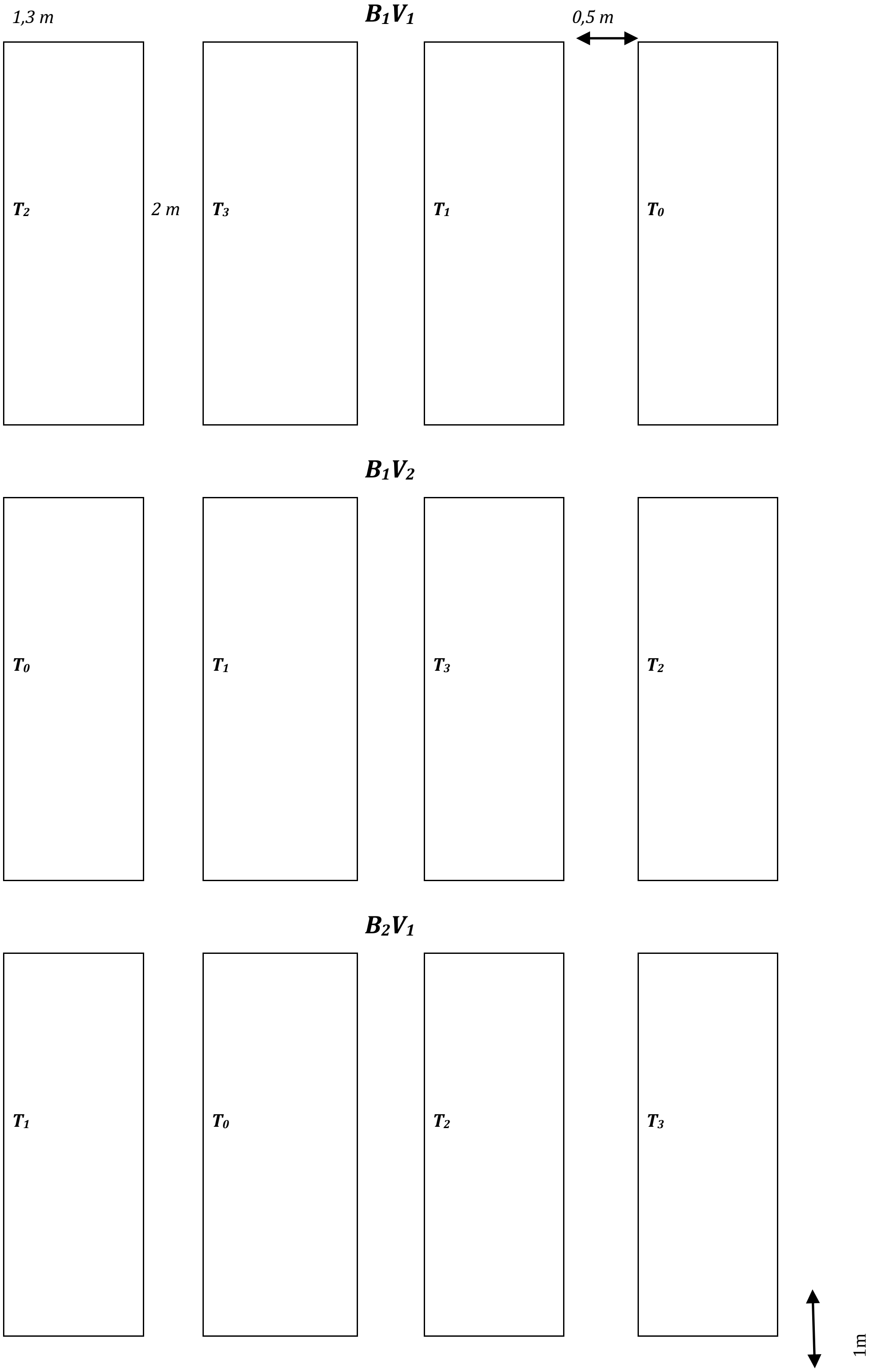
Figure 2 Varieties of *Abelmoschus esculentus*

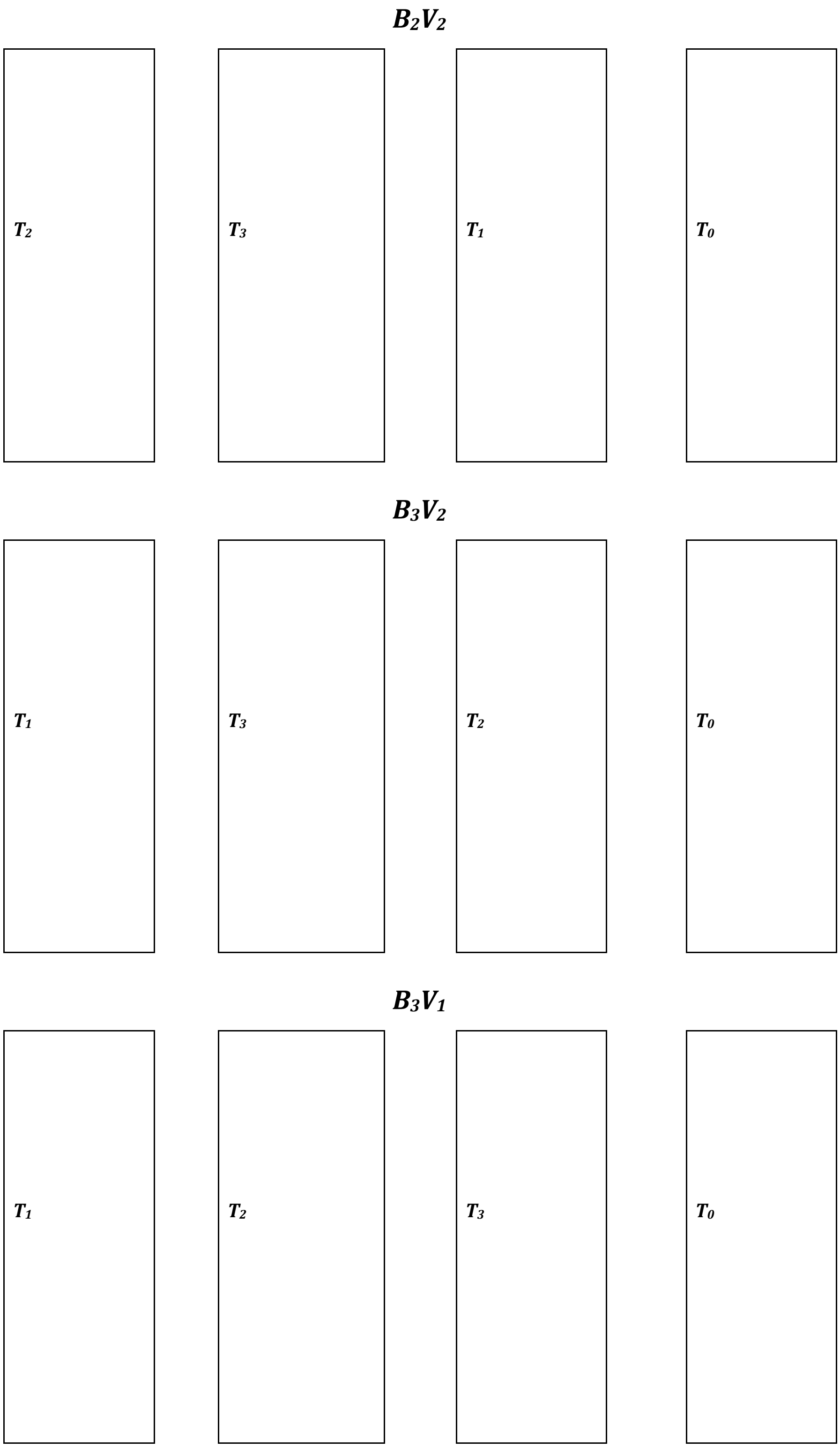
The erect variety had greenish colored fruits with very elongated capsules, petioles and whitish leaf veins. The rounded variety used had red-tinged green fruits with short, ovoid capsules, petioles and reddish leaf veins.

2.4 Experimental Design

The site, with an area of 8 x 15 m, is arranged in three blocks in an east-west direction. The two-factor experimental device adopted is that of the split plot (Figure 3). The randomized main factor (biofertilizer) is placed in the secondary plots while the secondary factor (variety) occupies the main plots after randomization. The aisle between two plots is

1 m. The dimensions of the secondary plots 0.5 m apart are 1.3 x 2 m. The trial, comprising four replicates spaced 1 m apart, had 12 main plots and 24 secondary plots.





Legend : B_1 : bloc1 ; B_2 : bloc 2 ; B_3 : bloc 3 ; V_1 : variété Indiana ; V_2 : variété Clemson spineless ; T_0 : Témoin ; T_1 : Biochar ; T_2 : Thé de compost ; T3 : Combinaison biochar et thé de compost.

Figure 3 Experimental Design

2.5 Technical itinerary

The conduct of the test consisted of the following operations: land clearing, stump removal, plowing with a hoe to a depth of about 30 cm, sowing and refilling of voids. The soil samples were taken before the application of the treatments and after the harvest in each sub-plot according to the diagonal method. They were mixed to form composite samples. The following edaphic parameters were measured: pHwater by the electrometric method, total nitrogen according to Kjedhal [14], assimilable phosphorus according to Olsen [15] and exchangeable potassium by atomic absorption spectrometry. Seeds soaked in water 24 hours before are sown 2 cm deep at a spacing of 0.60 x 0.80 m at the rate of three seeds per pocket. A week after sowing, we proceeded to refill the voids. Weeding, thinning and ridging took place three weeks after emergence. The biochar was buried at a depth of about 25 cm in the ground at a rate of 1 kg/pocket or 20 t/ha.

The vegetative and yield parameters measured are respectively the height of the plants, the diameter at the collar, the number of fruits and the weight of the fruits. Fruit harvesting was spread out during the vegetative cycle with one pass every 2 days.

The raw results of the experimental treatments, the relationships between the edaphic and biological parameters on the one hand and the edaphic and biological parameters on the other hand were respectively compared and determined using the SPSS: 20.

The economic profitability of the study was evaluated by the Marginal Rate of Return (MRR) method in accordance with the recommendations of [16].

3. Results

3.1 Soil parameters

Table 2 Soil parameters under different treatments

	Variables											
Treat	pHi	pHf	ΔpH	Ni (%)	Nf (%)	ΔN (%)	Pi (mg.kg^{-1})	Pf (mg.kg^{-1})	ΔPass (mg.kg^{-1})	Kéchi cmol (+).kg^{-1}	Kéchf cmol (+).kg^{-1}	ΔKéch cmol (+).kg^{-1}
T_0	4.16^a	4.03^a	- 0.13^a	0.11^a	0.95^a	0.84^a	5.32^b	4.76^a	- 0.562^a	2.34^b	2.22^a	-0.12^a
T_1	4.26^b	5.48^b	1.22^b	0.095^a	0.12^b	0.025^b	3.52^b	8.15^b	4.63^b	2.06^a	2.82^b	0.76^b
T_2	4.26^b	5.69^b	1.43^b	0.11^a	0.14^b	0.030^b	2.62^a	12.05^c	9.43^c	2.13^a	3.77^c	1.64^c
T_3	4.22^a	5.77^b	1.55^b	0.105^a	0.135^b	0.030^b	3.69^b	18.79^d	15.1^d	2.40^b	8.55^d	6.15^d

Legend: T0: Witness; T1: Biochar; T2: Compost Tea; T3: biochar*compost tea combination; pHi: soil pH before cultivation; pHf: soil pH after cultivation; Ni: Total nitrogen content of the soil before cultivation; Nf: Total nitrogen content of the soil after cultivation; Pi: Contents of assimilable phosphorus before cultivation; Pf: Contents of assimilable phosphorus after cultivation; Kechi: Contents of exchangeable potassium before culture; Kéchf: Contents of exchangeable potassium after culture; ΔpH: pH variation between the two stages; ΔN (%): variation in total nitrogen content between the two stages; ΔPass (%): variation in the levels of assimilable phosphorus between the two stages; ΔKéch: variation in the contents of exchangeable potassium between the two stages.

As an indicator of the status of the soil reaction [17] with significant training effect, the initial pH (Table 2) of our site is acidic and reveals major edaphic constraints such as the desaturation of the adsorbent complex [18, 19], phosphorus insolubilization [20]. The difference in water pH in the initial state between the control sub-plots (4.16) and that under the biochar*compost tea combination (4.22) is explained by the heterogeneity of the substrate. The same trend is observed for the pHH20 in the final state.

The removal of these constraints requires the addition of organic matter which significantly improves ($p < 0.05$) the variation in soil pH_{H20} by 1.22; 1.43 and 1.55 units respectively under T_1, T_2 and T_3. Biochar combined with compost tea through its acid and base functions, by forming mobile chelates with the acid ions in the root profile, improves soil pH and is an effective buffer with a zero charge point pH (pH_{pzc}) of 8. The presence of the microorganisms in compost tea (T_2) causes the rate of desorption of phosphorus from the binding sites of the adsorbent complex and thus increases the availability of assimilable phosphorus and exchangeable potassium for the culture in a ratio of 29.15 and 8 respectively under T_3/ T_0, T_2/ T_0 and T_1/ T_0. Under different treatments the ΔpH/ΔN ratios; ΔpH/ΔPass; ΔpH/ΔKech for the combination biochar*compost tea (T_3) are such that for an increase of 0.1 pH unit, the variations in nitrogen, assimilable phosphorus and exchangeable potassium are respectively 0.2%, 113, 6% and 434.8%.

By the mechanism of exchange with the ligands of the phosphorus adsorption sites, the organic anions on the one hand promote the desorption and the availability of phosphorus (r = 0.690) and on the other hand, by forming soluble chelates with the acid cations, responsible for the retrogradation of phosphorus raise the pH of the soil according to the model: $\Delta pH = 0.614 + 21.967\ \Delta N$ ($r^2 = 0.629$).

The tabl. 5 reveals a very significant correlation (0.959) between the dynamics of assimilable phosphorus and exchangeable potassium. Bivalent elements such as calcium present in organic colloids can release the potassium bound on the adsorbent complex into the soil solution.

The amendments made positively regulated the pH of the soil. The significant change (1.55) was observed under the biochar*compost tea combination. The buffering effects due to organic matter are greater than those found by [21] in a test in rice cultivation with the variation in pH (ΔpH) of – 0.56; – 0.73 and 0.16 respectively under the witness, compost and biochar. This improvement in pH has a considerable knock-on effect on the availability of nutrients [22].

3.2 Yield Parameters

The Kruskall-Wallis test on the different populations reveals significant differences between the treatments (table 6).

Table 3 Vegetative and production parameters of the Indiana (V1) and Clemson spineless (V2) variety of okra under different treatments

	Varieties									
	V_1					V_2				
	Nb	**Wt (g)**	**Yield (t.ha-1)**	**Diam (cm)**	**Height (cm)**	**Nb**	**Wt (g)**	**Yield (t.ha-1)**	**Diam (cm)**	**Height (cm)**
T_0	151^a	5248.00^b	20.2	8.10^a	15.50^a	228^b	4910.50^a	18.9	16.65^c	51.15^d
T_1	199^a	8623.20^d	33.2	10.40^b	21.81^b	344^d	8448.50^d	32.5	17.94^d	49.70^d
T_2	215^b	6609.80^c	25.4	9.46^a	15.85^a	237^b	5405.60^b	20.8	17.03^d	39.13^c
T_3	315^c	12313.00^e	47.4	13.40^b	24.85^b	342^d	8781.50^d	33.8	23.11^e	57.70^e

Legend: Nb : Number of fruits ; Weight: Fruit weight in grams;Yield: Yield in tonnes per hectare ; Diam :Diameter at the collar in cm of the plants;Haut :Height in cm of the plants.

From the point of view of the number of fruits, the *Clemenson spineless* variety gave on average, all treatments combined, 228 fruits against 220 fruits for the Indiana variety. This non-significant difference could be explained by the genetic potential of the materials. The individual effects of biochar and compost tea exceeded the control by 50.8% and 50%, respectively. The same trend is observed with regard to fruit weights. Table 7 reveals a very significant correlation (r = 0.793) between fruit number and fruit weight.

Table 4 Matrix of correlations between edaphic and biological parameters of the Indiana variety under biochar enriched with compost tea

	nombr	**poids**	**diam**	**haut**	**pHi**	**pHf**	**Ni**	**Nf**	**Passi**	**Passf**	**Kéchi**	**Kéchf**	**dpH**	**dN**	**dP**	**dKéch**
nombr	1															
poids	**.942****	1														
diam	**.951****	.562*	1													
haut	**.708****	**.963****	**.957****	1												
pHi	.502*	.476	.186	,259	1											
pHf	.543*	-.374	-.469	-,530*	-.544*	1										
Ni	.081	.036	-.053	-,012	.487*	.017	1									
Nf	.246	.317	-.254	-,120	.796**	-.155	.646**	1								
Passi	-.558*	-.426	-.425	-,501*	-.720**	.961**	-.173	-.369	1							
Passf	.556*	.427	.421	,497*	.735**	-.954**	.194	.388	-1.000**	1						
Kéchi	.556*	.428	.420	,497*	.737**	-.953**	.197	.391	-.999**	1.000**	1					
Kéchf	.555*	.427	.421	,497*	.735**	-.954**	.196	.388	-1.000**	1.000**	1.000**	1				
dpH	-.594*	-.460	-.415	-,488*	-.792**	.943**	-.180	-.428	.984**	-.985**	-.985**	-.985**	1			
dN	.398	.367	-.269	-,141	.507*	-.216	-.221	.602*	-.290	.293	.293	.291	-.358	1		
dP	.556*	.427	.422	**,498***	.733**	-.955**	.191	.385	-1.000**	1.000**	1.000**	1.000**	**-.985****	.292	1	
dKéch	.555*	.427	.421	.497*	.734**	-.954**	.195	.388	-1.000**	1.000**	1.000**	1.000**	-.985**	.291	1.000**	1

**: Significant values after the Pearson test ($p < 0.01$).

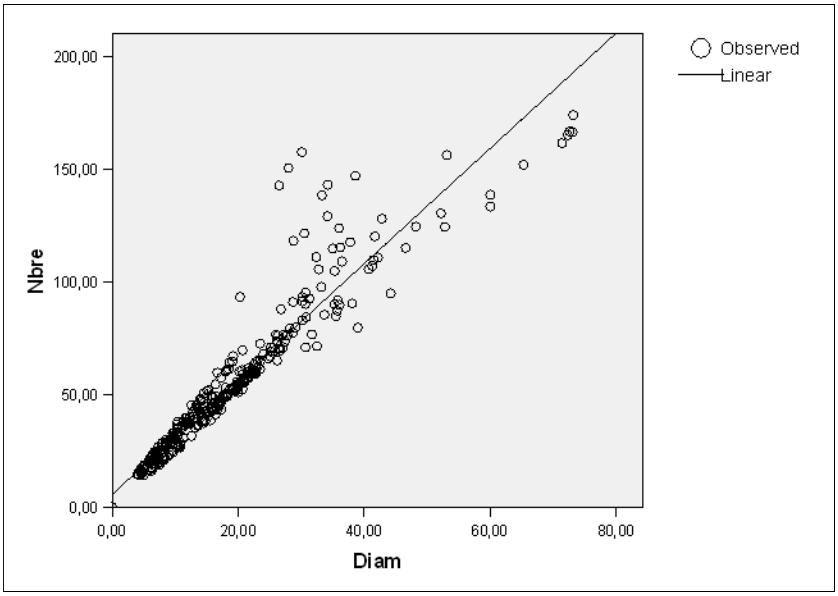


Figure 4 Relationship between collar diameter and number of fruits of the Indiana variety of okra under biochar (T2) and biochar enriched with compost tea (T3)

Y = 5,596 + 2,563 X avec R^2 = 0,905 (figure 6)

X: Okra collar diameter

Y: Number of Okra fruits

Figure 4 shows that there is a strong (0.905) and significant correlation at the 1% level between collar diameter and number of fruits. The linear model

Y = 5.596 + 2.563 X with R^2 = 0.905 indicates that the variation of one unit in diameter at the collar increases the number of fruits by 8 times and that the variation in diameter at the collar increases the variation in the number of fruits by 91%.

Also speculation based on the number of fruits will be based on increasing the diameter at the neck by adopting a relatively larger spacing than that adopted of 0.60 x 0.80 m. On the other hand, a narrower spacing will promote competition between the plants with regard to light and will induce greater growth in height and, if necessary, rather an increase in the weight of okra fruits according to the model Y = 7.666 + 2.445 X (Figure 7).

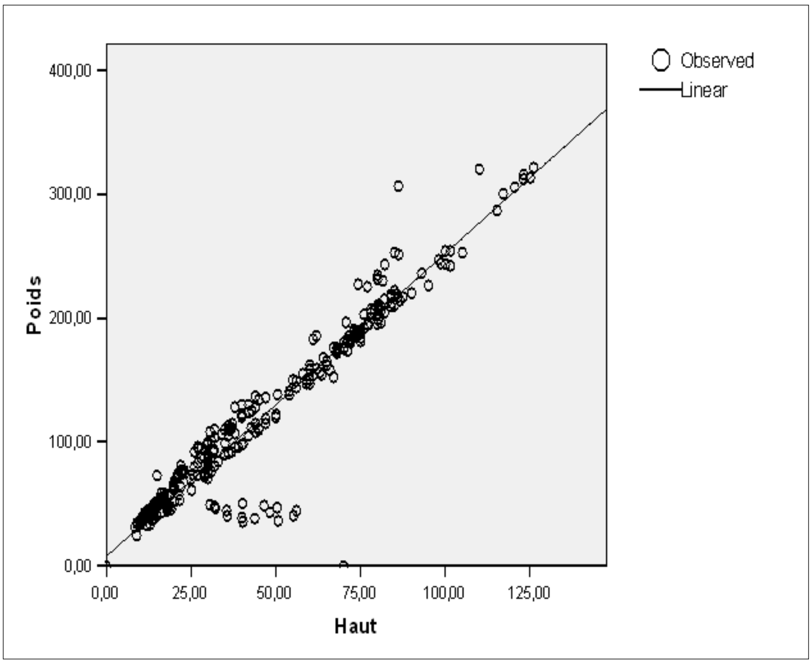


Figure 5 Relationship between plant height and fruit weight of the Indiana variety of okra under biochar (T2) and biochar enriched with compost tea (T3)

Y = 7,666 + 2,445X avec R^2 = 0,927.

X: Height of Okra plants

Y: Okra fruit weight

Furthermore, a strong positive correlation was observed between the weight of the fruits and the number of fruits (r = 0.942). The latter is influenced by the height of the plants (r = 0.708). This means that the greater the growth in height, the more flower buds there are. Table 7 further shows a significant correlation (r = +0.498) between plant height and phosphate nutrition influenced by pH variation (r = -0.985). By improving the reaction of the soil, the T_2 and T_3 treatments make available the assimilable phosphorus and induce the height growth of the plants of the Indiana variety.

The financial efficiency indicators shown in Tables 8 and 9 reflect economic performance expressed by marginal rates of return greater than 1. Under the biochar * compost tea combination, the value of the Benefit / Cost Ratio being 4.4 indicates that 1 US$ invested in the biofertilization of the *Indiana* variety of okra yields 4.4 US$. The Marginal Rate of Return of 0.73 for the *Clemson spineless* variety demonstrates that the production system is not financially profitable. It will then be a question of improving farming techniques with a view to increasing production.

Table 5 Effects of different treatments on the financial profitability of the Indiana variety of okra

	T_0	T_1	T_2	T_3
Cout total (US $)	675	907.5	1320	1735
Cout marginal (US $)	-	232.5	645	1060
Rendement (t. ha-1)	20.32	22.78	29.35	43.64
Δ Rendement (t. ha-1)	-	2.46	9.03	23.32
Bénéfice Δ Rendement (US $)	-	492	1 806	4 664
Ratio Cout/Bénéfice (RCB)	-	0.47	0.35	0.22

Table 6 Effects of different treatments on the financial profitability of the Clemson spineless variety of okra

	T_0	T_1	T_2	T_3
Cout total (US $)	675	907.5	1320	1735
Cout marginal (US $)	-	232.5	645	1060
Rendement (t. ha^{-1})	18.9	20.8	22.5	33.8
Δ Rendement (t. ha^{-1})	-	1.9	3.6	14.9
Bénéfice Δ Rendement (US $)	-	380	720	2 980
Rapport Cout/Bénéfice (RCB)	-	0.61	0.89	0.35

4. Discussion

The substrate of our test with a pHH2O in the initial state varying from 4.16 to 4.26 is characteristic of soils with low fertility [23]. In an experiment cited by [24], the application of 150 t/ha of municipal organic waste to acidic soil raised its pH from 3.3 to 6.7 after 18 months. Despite the buffering capacity of the soil, the use of 150 t/ha instead of 20 t/ha as in our study could improve the pH more effectively.

The initial values of assimilable phosphorus (in ppm) of our site (T_0 = 5.32; T_1 = 3.52; T_2 = 2.62; T_3 = 3.69) are lower than the values found in the savanna zone by [25] are 7 mg.kg−1 in Kimwenza; 13 mg.kg−1 at Mont-Amba and 15 mg.kg−1 at Balume. These different values are lower than the guide values for tropical soils (15 ppm) and indicate a phosphorus deficiency in the soils. The deficiency of phosphorus in the humid tropical zone could be explained by the presence of oxyhydroxides, responsible for its retrogradation in the soil.

Average yields vary between 4 to 8 t/ha in Kenya, Sudan, Gabon and Ivory Coast, 10 to 15 t/ha in Cape Verde, 10 to 20 t/ha in Mali and 15 to 20 t/ ha in Mauritania, Senegal and Tchad [26]. Our trial in Kisangani (North East of the DRC) gave variable yields depending on the variety and the treatments. For the Indiana variety, the average yields are 20.2 t.ha-1 under T0, 33.2 t.ha-1 under T1; 25.4 t.ha-1 under T2 and 47.4 t.ha-1 under T3. The Clemson spineless variety gives average yields of around 18.9 t.ha-1 under T0; 32.5 t.ha-1 under T1; 20.8 t.ha-1 under T2 and 33.8 t.ha-1 under T3. [27] found yields of 11.26 t. ha-1 for the Shirangevee variety; of 2.70 t. ha-1 for the Rouge de Thiès variety; of 3.06 t. ha-1 for the Clemson spineless variety; 6.36 t ha-1 for the F1 Lima variety; 5.05 t ha-1 for the Volta variety. These yields are lower than the potential theoretical yield of Senegalese varieties, which varies between 8 and 20 t ha-1. [28] found in the pedoclimatic and socio-economic conditions of Lubumbashi (DR Congo) an average okra yield of 3.3 t.ha-1 against 6.5 t.ha-1 in the cooperativized market gardening sites of Kinshasa in DR Congo [29].

Regarding the marginal rate of return, [28] found a very low rate of 0.09 of okra cultivation in Lubumbashi against 1.2 in Kinshasa [30]. [31] reports that the benefit/cost ratio in Benin is 1.9 compared to 3.1 for all treatments combined for the Indiana variety for our trial, which is more financially profitable.

5. Conclusion

The objective of our study is to evaluate the effects of compost tea-enriched biochar on soil response, nutrient availability, and productivity performance of Indiana and Clemson spineless varieties of *Abelmoschus esculentus* in urban agriculture at Kisangani.

In fact, in acidic soils, before any mineral fertilization, the classic technical route for conducting a trial involves the addition of limestone amendments in okra cultivation, the optimum pH of the soil of which varies from – to 6.8. Due to its pH_{pHi} of 8 and its surface functions, the biochar enriched with compost tea contributes to the pedogenesis of a part, is revealed as well as a limestone amendment but also as a biofertilizer by the contribution of nutrients from the microorganisms on the other hand. The recycling of crop residues in the form of biochar and compost tea constitutes biofertilizers with sustainable effects and after-effects in urban and peri-urban agriculture, likely to generate substantial revenue (TMR varying from 2.1 to 4.4).

Compliance with ethical standards

Acknowledgments

We would like to thank the technicians of the Soil Science laboratories of the University of Kisangani, of Microbiology and Organic Chemistry of the University of Kinshasa.

Disclosure of conflict of interest

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

References

[1] Melgar RJ, Smyth TJ, Sanchez PA, Cravo MS. Fertilizer nitrogen movement in a Central Amazon Oxisol and Entisol cropped to corn. Fert. Res. 1992; 31: 241-252.

[2] Cahn MD, Bouldin DR, Cravo MS, Bowen WT. Cation and nitrate leaching in an Oxisol of the Brazilian Amazon. Agron. J. 1993; 85: 334-340.

[3] Glaser B, Lehr VI. Biochar effects on phosphorus availability in agricultural soils: A metaanalysis. Sci. Rep.2019 ; 9(1) : 1–9.

[4] Lehmann J, Gaunt J, Rondon M. Biochar sequestration in terrestrial ecosystems–a review. Mitigation and Adaption Strategies for Global Change. 2006; 11: 395–419.

[5] Wardle DA, Nilsson MC, Zackrisson. Fire derived charcoal causes loss of forest humus. Science. 2008; 320: 629–621.

[6] Verheijen F, Jeffery S, Bastos AC, van der Velde M, Diafas I. Biochar Application to Soils : A Critical Scientific Review of Effects on Soil Properties, Processes and Functions. Publications.jrc.ec.europa.eu:2010.

[7] Novak M, Busscher J, Watts W, Laird D, Ahmedna A, Niandou AS, 2010. Short-term CO2 mineralization after additions of biochar and switchgrass to a typic kandiud-ult. Geoderma. 2010; 154:281–288.

[8] Liang B, Lehmann J, Solomon D. Black carbon increases cation exchange capacity in soils. Soil Science Society of America Journal. 2006; 70, 1719–1730.

[9] Laird DA, Fleming P, Davis DD, Horton R, Wang B, Karlen DL,. Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. Geo-derma. 2010b; 158, 443–449.

[10] Saito M., 1990. Charcoal as a micro-habitat for VA mycorrhizal fungi, and its practical implication. Agric. Ecosyst. Environ. 1990; 29(1–4): 341–344.

[11] Kimetu JM, Lehmann J, Ngoze SO. Reversibility of soil productivity decline with organic matter of differing quality along degradation gradient.Eco-systems. 2008; 11: 726–739.

[12] Spokas KA, Baker JM, Reicosky DC. Ethylene: potential key for biochar amendment impacts. Plant and Soil. 2010; 333: 443–452.

[13] Baert G, Van Ranst E, Ngongo ML, Kasongo EL, Verdoodt A, Mujinya BB, Mukalay JM. Guide des sols en R.D.Congo. Tome II : Description et Données physico-chimiques des profils types. Ugent, Hogent, Unilu. Lubumbashi: 2009.

[14] Van Ranst E, Verloo M, Demeyer A, Pauwels JM. Manual for the soil chemistry and Fertility Laboratory.University of Ghent: 1999.

[15] Olsen SR, Cote CV, Watanabe FS, Dean LA, Estimation of available phosphorus in soils by extraction with sodiumbicarbonate. U.S.D.A. Circular 1954; 939: 8 p

[16] CYMMIT. Formulation de recommandations à partir de données agronomiques. Manuel méthodologique 'évaluation économique. Edition totalement révisée. Mexico: 1989.

[17] Nguemezi C,Tematio P, Yemefack M,Tsozué D, Silatsa F. Soil quality and soil fertility status in major soil groups at the Tombel area, South-West Cameroon.Heliyon.2020; 6(2): 10 p.

[18] Omatayo OE, Chukwuka KS. Soil fertility restoration techniques in Sub-saharan Africa using organic resources. African journal of Agricultural research. 2009; Vol 4, 3: 144 -150.

[19] Kasongo KR, Kanyankogote MP, Disa Disa P, Baert G, Van Rast E. Improvement of surface load properties of heavily weathered soils in the Kinshasa hinterland by application of Kimpese pink dolomite and coffee parchment. Congo Science. 2021; 9 (1): 16 – 31.

[20] Sabry MS, Jörg R. Influence of common ions on sorption and mobility of soil phosphorus. Book Phosphate in soils. 1st Edition: 2015.

[21] Merelle F. Soil analysis today. Nantes, France: GEMAS Edition: 1998

[22] Igue A.M, Saidou A, Adjanohoun A, Ezui G, Atiogbe P, Kpagbin G, Gotoechan – Hodonon H, Youl S, Pare T, BalogouI, Ouedraogo J, Dossa E, Mando A, Sogbedji J.M. Assessment of soil fertility in the south and central Benin. Benin Agricultural Research Bulletin. TropicAgrif. 2013; 12 – 23.

[23] Lochon I. Effects of liming on the functioning of the grassland ecosystem in mid-mountains. Doctoral thesis. Grassland Ecosystem Research Unit (UMR874), Clermont-Ferrand: 2018.

[24] Mbonigaba, J. J. Study of the impact of plant biomass-based composts on the dynamics of physico-chemical, chemical and microbiological indicators of soil fertility: Application to three tropical acid soils in Rwanda. Doctoral thesis. Gembloux, Belgium, University Faculty of Agricultural Sciences: 2007.

[25] Mulaji C, Disa – Disa P, Kibal I, Culot M. Diagnosis of the agropedological state of acid soils in the province of Kinshasa in the Democratic Republic of Congo (DRC). Chemistry reports. 2016; 19 (7): 820-826.

[26] DeLannoy. Vegetables-fruits. Agriculture in Tropical Africa. Romain H. Raemaekers, 2001: 478 – 484.

[27] Thiaw M. A, Ndiaye D, Séne M, Mbaye T, Baldé M. Yield evaluation of six varieties of okra (Abelmoschus esculentus (L.) Moench) under the agro-climatic conditions of Sédhiou in Senegal. African Journal of Environment and Agriculture. 2019; 2(1): 69-75.

[28] Tshomba J, Esoma B, Muyambo E, Useni Y, Nyembo L. Factors influencing the profit from okra cultivation in the pedoclimatic and socioeconomic conditions of Lubumbashi in the DRC. International Journal of Innovation and Applied Studies, 2015; Flight 12; No. 4: 820-830.

[29] Muzingu B. 2010. Cooperativized market gardening sites in Kinshasa in DR Congo. Environmental constraints and actors' strategies. Doctoral thesis, Louvain-la-Neuve, Catholic University of Louvain: 2010.

[30] Kasongo LME, Yumba KG. Study of peri-urban agriculture in Kinshasa. Action Against Hunger – Democratic Republic of Congo. 2009. 87 p.

[31] Safiri A.H.I. Efficiency of okra production units in the commune of Kèrou, Department of Atacora, Benin. University of Abomey-calavi, Benin: 2016.