Original Research Article

STUDY OF THE EFFECT OF BIOCHAR INCUBATION ON SOME PHYSICO-CHEMICAL PROPERTIES OF A TROPICAL LEACHED SOIL FROM SOUTH-WEST CHAD

ABSTRACT

Soils in the Sudanian zone of Chad, and more specifically leached tropical soils, were subject to physical and chemical degradation phenomena that hamper crop production. Solving this problem requires solutions for the rational improvement of fertility. The aim of this study, conducted in a controlled environment, was to assess the fertilising potential of biochar on impoverished soil by monitoring the kinetics of the evolution and release of chemical elements that improve the physico-chemical quality of the soil. Four treatments were carried out: control soil (T0), treatment 1B: 100g soil + 0.225g biochar (i.e. 5 t/ha), treatment 2B: 100g soil + 0.3375g biochar (i.e. 7.5 t/ha) and treatment 3B: 100g soil + 0.450g biochar (i.e. 10 t/ha). Each treatment was repeated four times. Four main parameters were measured during the trial period: pH, assimilable phosphorus, exchangeable bases and their sums (Ca, Mg, K, Na and SBE) and cation exchange capacity. These different parameters showed that the biochar treatments significantly improved soil quality, whatever the dose and incubation time, compared with the T0 control. Treatment 1B (5t/ha biochar application) increased pH by an average of 6.5%, phosphorus by 132.5%, SBE by 406.1% and CEC by 43.4%. Treatment 2B (application of 7.5 t/ha of biochar) improved pH by an average of 8.5%, phosphorus by 155.1%, SBE by 207.6% and CEC by 46.2%. Treatment 3B (application of 10t/ha of biochar) produced a marked improvement, increasing pH by 11.2%, phosphorus by 198.7%, SBE by 457.6% and CEC by 29.9%. These results further confirm the vital importance of biochar in fertilising impoverished tropical soils. Based on pH, sum of bases and phosphorus, treatment 3B gave better results by considerably increasing the initial chemical element content of the control soil than the other biochar treatments.

Keywords: biochar, incubation, physico-chemical properties, tropical soil, Chad.

1. INTRODUCTION

Population growth and the lack of arable land in Sub-Saharan Africa are one of the main causes of over exploitation of land, leading to land degradation [1,2]. The resulting consequences are soil nutrient deficiencies [3]. Compensating for this reduction/ deficiencies due to the removal of nutrients by plants or to degradation phenomena means applying appropriate soil fertilisation techniques. The use of chemical fertilisers is one of the most widely used fertilisation methods. However, in addition to their polluting effect, chemical fertilisers are inaccessible and expensive for African farmers, who are often very poor [4,5,6,7]. Other techniques for improving soil fertility, in particular improved fallow, crop rotation and intercropping, are good ways of restoring and improving soil productivity. However, they no longer appear to be effective in the long term given the current context of climate change, population growth and other factors contributing to food insecurity [8]. Hence the need to set up a sustainable and productive agricultural system that is essential, efficient and environmentally friendly, with the aim of restoring soil fertility using organic amendments in order to guarantee food security for the population. Several authors around the world have demonstrated that organic amendments can maintain or improve soil fertility in more sustainable ways [9,10,11,12,13,14]. With this in mind, incubation trials of biochar on a depleted tropical leached soil were conducted in the laboratory with the aim of assessing the potential of this fertiliser by monitoring physico-chemical parameters over a given time scale.

2. MATERIALS AND METHODS

2.1 Presentation of the soil sampling site

The site from which the soil samples were taken is located in the Sudanian zone of Chad, between latitudes 9°12' and 9°24' North and longitudes 14°48' and 15°0' East (Fig. 1). The climate is Sudano-Guinean, with average annual rainfall of 1,000 mm [15,16,17]. The area's hydrographic network is made up of a number of fairly large streams, generally known as « Mayo or El », which run off the hills and form marshy areas at low points [18]. The vegetation is the Sudano-Guinean domain and a grouping of vegetations from several domains, the main ones being the wooded savannah, the very open wooded savannah, the vegetation consisting of relics of cultivated areas and the massif vegetation [19,20]. The soil type on which the samples were taken is a ferruginous soil with a sandy-loamy texture [21]. Alongside this soil are other sesquioxide soils, hydromorphic soils, crude mineral soils, soils with little development and the juxtaposition of several soil types or classes [22,23]. The geology of the area consists mainly of outcrops of basement, continental terminal, Cretaceous and Quaternary formations [24].

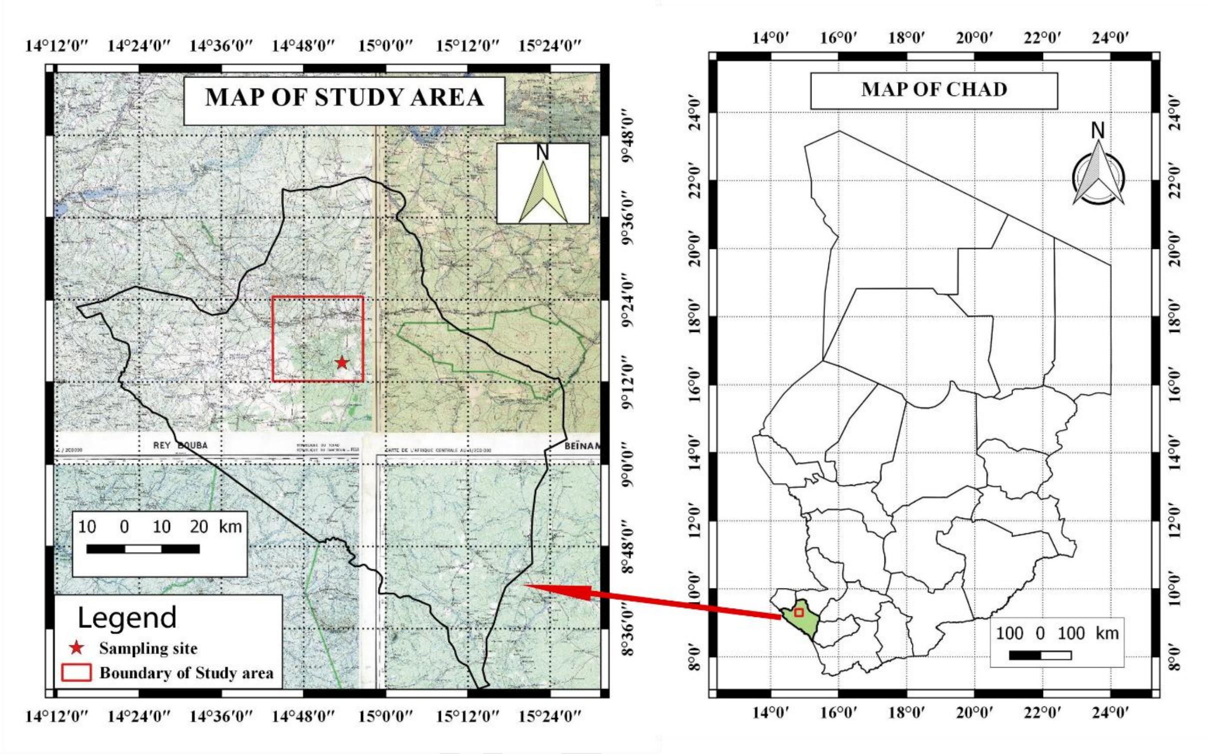

Fig. 1. Location map of soil sample collection site for incubation study

2.2 Soil material

Samples were taken from the surface horizons (0-25 cm) and were taken systematically. All the soil samples taken were dried and then mixed. They were turned over as many times as possible to ensure a good mix and to obtain a homogeneous sample. The sample was then quartered. The two diagonals were then mixed and used in pots 7 cm high and 4 cm in diameter, giving a volume of 87.92 cm^3.

2.3 Organic fertilizer: biochar

The fertiliser used is biochar, the original material of which is millet stalks. It was ground in a porcelain mortar and sieved using a stainless steel sieve to obtain particles with dimensions of 2mm or less for laboratory analysis and for use in incubation tests.

2.4 Soil and biochar analysis methods

The soil and biochar were subjected to physico-chemical analysis at the Laboratory of the Faculty of Agronomy and Agricultural Sciences (FASA) of the University of Dschang and at the Laboratory for the Analysis of Soil, Water and Soil at the Chadian Institute of Agronomic Research for Development (ITRAD). These physico-chemical analyses were carried out on samples smaller than 2 mm. For the physico-chemical analyses, the pH was determined using the soil solution method with a soil/water ratio of 1/2.5. Granulometry was determined using the densimetric method. Exchangeable bases and CEC were determined using the method described by [25], which involves extracting exchangeable bases and then determining CEC from the same soil sample. Assimilable phosphorus was determined using the Bray 1 method.

2.5 Experimental design and conduct of trials

The experimental set-up consisted of a block of four (04) treatments. Each treatment consisted of 09 units repeated 3 times. A total of 108 experimental units. In each pot corresponding to an experimental unit, 100 g of soil were mixed with 0.225 g (i.e. 5 t/ha), 0.3375 g (7.5 t/ha) and 0.450 g (10 t/ha).

The treatments were as follows:

- T0: control with no fertiliser ;
- 1B: treatment with 5 t/ha of biochar;
- 2B: treatment with 7.5 t/ha of biochar;
- 3B: treatment with 10 t/ha of biochar.

The trials were conducted at the Laboratory of the Chadian Institute of Agronomic Research for Development under controlled conditions. The treatments were subjected to the same conditions, with regular injections of 20 ml of demineralised water every seventy-two hours into each unit in order to maintain the soil at field capacity. Samples for analyses to monitor changes in physico-chemical parameters were taken at zero (corresponding to the T0 control), one (1), two (2), four (4) and six (6) months of incubation. For each treatment, three random pot samples were taken at each period indicated and then mixed to form a sample for physico-chemical laboratory analysis.

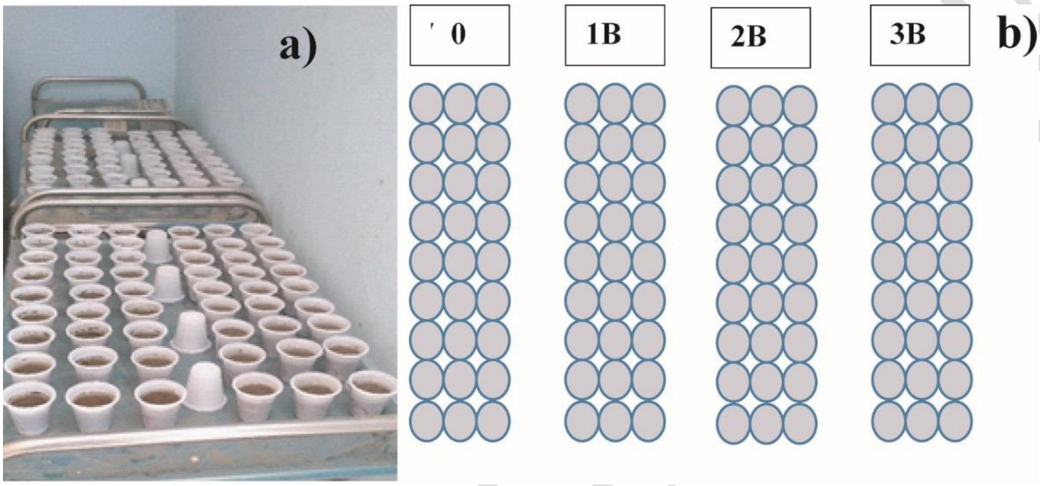

Fig. 2. a) Photo of the test line, b) Experimental design

3. RESULTS

3.1 Physico-chemical characteristics of soil and biochar

The physico-chemical characteristics of the control soil (corresponding to T0) and the biochar are shown in Table 1.

The soil has a sandy-loam texture, a slightly acid pH (6.90), very low Ca and Na content (1.0 and 0.02 meq/100g respectively), low Mg (1.2 meq/100g) and average K (0.4 meq/100g). The CEC is average (18.2 meq/100g). SBE and V are low (2.6 and 14.51 meq/100g, respectively).

The biochar has an alkaline pH (9.22), a very high Ca and Mg content (100.4 and 60.4 meq/100g, respectively), high K (0.98 meq/100g) and low Na (0.22 meq/100g). CEC and SBE levels are very high. V is high at 79.75%.

Table 1: Physical and chemical parameters of soil and biochar samples

Samples	**Sand**	**Silt**	**Clay**	**pH$_{eau}$**	**P ass**	**Ca**	**Mg**	**K**	**Na**	**CEC**	**SBE**	**V**
	%				ppm	in meq/100						en %
Control T0	71	16	13	6.9	0.5	1.0	1.2	0.4	0.02	18.2	2.6	14.51
Biochar	na	na	na	9.22	78.3	100.4	60.4	0.98	0.22	203.12	162.0	79.75

NB: P ass: Assimilable phosphorus; na: not analysed ; SBE : Sum of Exchangeable Bases ; V : Saturation rate ; CEC : Cationique Exchange Capacity

Table 2. Evolution of pH, exchangeable bases, CEC and saturation rate as a function of doses and incubation test time of biochar in the soil compared with the control.

Treatments and duration of incub	**pH**	**P ass**	**Ca^{2+}**	**Mg^{2+}**	**K^{+}**	**Na^{+}**	**SBE**	**CEC**	**V** en %

			ppm	meq/100g of soil						
Control	T0	6.90	3.6	1.0	1.2	0,4	0.02	2.6	18.2	14.51
1 month	1B	7.32	9.6	8.56	1.36	1,48	0.29	11.69	23.20	50.39
	2B	7.50	10.7	1.36	1.36	3,85	0.63	7.19	25.60	28.09
	3B	7.78	11.2	2.24	6.08	2,38	0.36	11.06	23.20	47.65
2 months	1B	7.44	8.9	10.56	17.36	4,31	0.49	32.72	38.00	86.11
	2B	7.61	10.8	1.20	2.32	1,83	0.36	5.70	24.80	22.99
	3B	7.74	12.7	10.56	17.36	1,32	0.29	29.53	32.16	91.81
4 months	1B	7.38	8.2	1.76	4.00	1,32	0.22	7.30	22.40	32.58
	2B	7.42	6.6	1.76	4.00	2,98	0.36	9.09	26.40	34.45
	3B	7.53	9.0	3.60	1.28	4,79	0.49	10.16	20.00	50.82
6 months	1B	7.26	6.7	1.76	2.16	2,57	0.36	6.85	20.80	32.93
	2B	7.42	8.6	1.36	6.00	2,28	0.36	10.00	29.60	33.78
	3B	7.65	10.2	1.76	2.56	2,57	0.36	7.25	19.20	37.76

3.2 Effects of biochar on physico-chemical parameters

3.2.1 Effect of biochar on pH

The effect of biochar on hydrogen potential (pH) is shown in Figure 3. The pH of all treatments (7.26 to 7.87) increased by 0.36 to 0.97 units, i.e. a rate of 5.2 to 12.8% whatever the incubation time compared with the control (6.90). Treatments 1B and 2B show the highest pH peak after 2 months of testing. Treatment 3B showed a better result after 1 month of testing. The evolution is such that for the same duration, the pH is strongly linked to the doses: the higher the dose, the higher the pH, but independently of the incubation duration.

All in all, the best result of all the treatments was observed with treatment 3B, which showed an average increase of 11.2%. Treatments 2B and 1B showed an average increase of 8.5 and 6.5% respectively. The pH improvement is summarised as a function of the treatments applied, such as 3B>2B>1B.

3.2.2 Effect on assimilable phosphorus

The effect of incubating biochar in the soil on the level of available phosphorus is shown in Figure 3.

Phosphorus levels changed as a function of dose at 1, 2 and 6 months. However, at 4 months of incubation, the rate changes in a jagged fashion.

Treatment 1B gave the best results after 1 month's testing (9.6 ppm), then the rate fell as the incubation time increased, reaching a rate of 6.7 ppm after 6 months' testing.

Treatments 2B and 3B showed the best results in months 1 and 2 of the incubation trial (10.7 and 10.8 ppm respectively for 2B; 11.2 and 12.7 ppm for 3B respectively), then decreased after 4 months (6.6 and 9.0 ppm respectively for 2B and 3B), before increasing to 8.6 and 10.2 ppm (respectively for 2B and 3B) after 6 months of the trial.

All the biochar treatments contributed to improving soil phosphorus levels by between 83.6 and 252.2% compared with the control (3.6 ppm). Specifically, treatment 1B improved from 86.6 to 167.9%, treatment 2B increased from 83.6 to 201.0% and finally treatment 3B increased from 149.8 to 252.2%.

In summary, based on average phosphorus levels, the best results were observed in treatment 3B (10t/ha), where 3B> 2B> 1B.

3.2.3 Effect of biochar on exchangeable bases

Figure 3 shows the content of base sums in the various treatments over the six-month period.

Treatment 1B has SBE contents ranging from 6.9 to 32.7 meq/100g. This content increases exponentially after 1 and 2 months of testing (11.7 and 32.7 meq/100g respectively) then decreases drastically after 4 and 6 months (7.3 and 6.9 meq/100g respectively).

The results of treatment 2B show SBE levels ranging from 5.7 to 10.0 meq/100g. This content decreased to 5.7 meq/100g at 2 months, after reaching 7.2 meq/100g at 1 month, and then increased after 4 months until the 6th month (contents of 9.1 and 10 meq/100g respectively).

Treatment 3B showed values between 7.3 and 29.5 meq/100g. The SBE content increases exponentially during months 1 and 2 (11.1 to 29.5 meq/100g respectively) then drops drastically after 4 and 6 months of testing to 10.2 and 7.3 meq/100g respectively.

In summary, the results indicate that all the biochar treatments significantly increased the SBE content from 178.8 to 1158.5% compared with the control, irrespective of the duration of the trial, which was not strongly dose-dependent. Treatment 1B improved with a rate varying from 163.5 to 1158.5% compared with the T0 control. Treatment 2B increased from 119.3 to 284.6% and treatment 3B improved from 178.8 to 1035.6% compared with the control.

Based on the average SBE, the best results were observed in treatment 1B (an average of 463.1%) followed by treatment 3B, as 1B>3B>2B.

3.2.4 Effect on CEC

The CEC contents from the incubation trials are shown in Figure 3.

Treatment 1B has a CEC content that varies from 20.8 to 38.0 meq/100g, i.e. an increase of 14.3 to 108.8% compared with the T0 control. This content increased in the trials at 1 and 2 months of incubation (23.2 and 38.0 meq/100g respectively) then fell after 4 and 6 months of testing (22.4 and 20.8 meq/100g respectively).

Treatment 2B showed CEC values ranging from 24.8 to 29.6 meq/100g, i.e. an increase of 36.3 to 62.6% compared with T0. The content increased overall with the duration of the incubation trial, although it decreased slightly in the 2nd month.

Treatment 3B showed values between 19.2 and 32.2 meq/100g, corresponding to an increase in content of 5.5 to 76.7% compared with the control. The CEC content increased in months 1 and 2 of the trial (23.2 and 32.2 meq/100g respectively) and then gradually decreased after 4 and 6 months (20.0 and 19.2 meq/100g, respectively).

Overall, the results obtained indicate that all the biochar treatments significantly increased the CEC content by 5.5 to 108.8% compared with the control, whatever the dose and duration of the trial. The best results were observed in treatment 2B, with an average increase of 46.2%. Thus, the order is 2B>1B>3B.

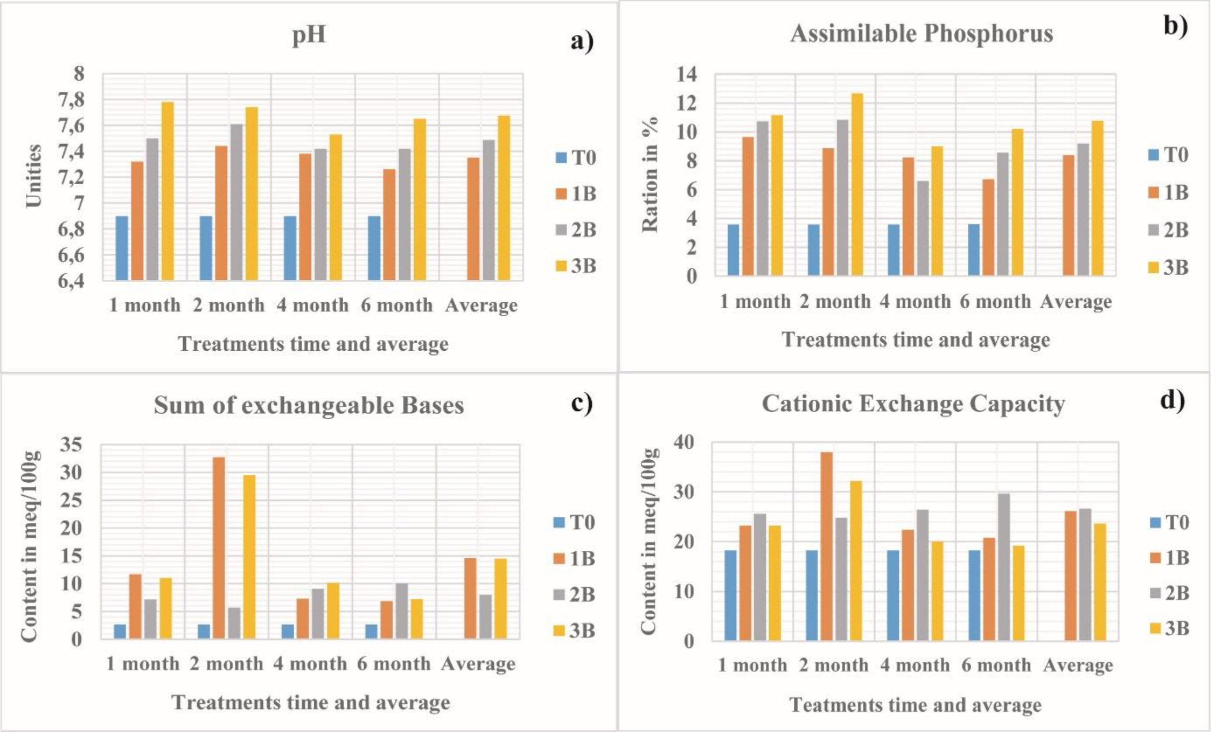

Fig. 3. Variation in pH (a), assimilable phosphorus (b), sum of exchangeable bases (c) and cation exchange capacity (d) diagrams.

3.3 Statistical analysis

Table 3. Correlation matrix between the various physico-chemical parameters obtained from the tests

Variables	pH	P	Ca^{2+}	Mg^{2+}	K^+	Na^+	SBE	CEC	V
pH	1								

P	.901**	1							
Ca^{2+}	.201	.383	1						
Mg^{2+}	.358	.371	.759**	1					
K^{+}	.318	.188	.092	.091	1				
Na^{+}	.526	.510	.097	.099	.875**	1			
SBE	.360	.423	.897**	.951**	.250	.241	1		
CEC	.296	.354	.655*	.860**	.267	.358	.849**	1	
V	.460	.511	.914**	.874**	.268	.249	.962**	.706**	1

*****. Correlation is significant at the 0.01 level (two-tailed).***

****. Correlation is significant at the 0.05 level (two-tailed).***

Table 3 shows the correlation matrix between the various physico-chemical parameters studied. It shows the various correlations that exist between them, although they are not significant in most cases. All the parameters are practically correlated. However, pH is strongly positively correlated with assimilable phosphorus (r=0.901). Calcium and magnesium are strongly positively correlated with each other (r=0.759) and with SBE (r=0.897 and r=0.951). Potassium and sodium are strongly positively correlated with each other (r=0.875). CEC was very strongly positively correlated with SBE (r=0.849) and positively correlated with calcium (r=0.655).

4. DISCUSSION

4.1 Physico-chemistry of the control soil and biochar

The soil used for the controlled incubation trial has a sandy-loam texture, a slightly acid pH, very low Ca and Na content, low Mg content and average K content. The CEC is average. SBE and V are low. The work of [26] in the area gave similar results and he concluded that these soils had poor to very poor fertility overall. [21] mentioned the fact that this low fertility was linked to overexploitation of the land, with plants taking nutrients without restoring them to compensate. These same authors [21] have also shown that this soil has a very high chemical weathering index (87.1) and a significant mineralogical weathering index (74.2). The weathering indices appear to be correlated with the granulometry of this soil, which has a sandier texture (71%) and low clay content (13%). These results confirm the descriptions by [23] that these soils are highly leached.

The biochar has an alkaline pH, a very high Ca and Mg content, a high K content and a low Na content. CEC and SBE are very high. The V saturation rate is high. Similar results, particularly for biochar, have been reported by [27,26,28,29,30,31].

4.2 Effects of biochar on physico-chemical parameters

The application of biochar had a very positive effect on pH, increasing it from 0.36 to 0.97 units regardless of the duration of incubation; however, the 10t/ha treatment (3B) gave better results compared with the other treatments (1B and 2B) and the control. Thus, whatever the dose, biochar had a positive effect on soil pH. This increase in the pH of the amended soils is thought to be due to the initial pH of the biochar, which is 9.22. Several studies, notably those by [30] on sandy soils in Kinshasa and [32] on leached soils in Cameroon, have produced similar results. [30] achieved an increase in pH ranging from 0.89 to 0.95 units compared with the control. However, the increase in pH was not proportional to the dose, because based on the 5t/ha application compared with the control, we did not obtain an increase in the unit multiplied by 1.5 or 2 when the dose was multiplied by 1.5 and 2, i.e. at 7.5 and 10t/ha. This could be explained by the fact that the more the dose is multiplied by 1.5 or 2, the release of certain chemical elements by the biochar would be at the origin of the relatively buffer effect not allowing a very drastic increase in pH after reaching a certain threshold. Furthermore, some authors [33] have studied the application of fertilisers at 10, 20 and 30% and have found that the increase in pH units is not proportional to the dose when it is doubled or tripled.

Assimilable phosphorus levels were significantly improved in soils treated with biochar, irrespective of incubation time and dose, compared with the control. This significant increase could be linked to the direct effect of the biochar or indirectly to the fact that the biochar had a positive effect on pH, which favours phosphorus availability in tropical soils. Moreover, pH and phosphorus are highly positively correlated (r=0.901). [34] have shown that phosphorus can be blocked at acid pH in tropical soils and that it is made available at pH between 6 and 8. Similarly, [35,36] demonstrated that conversion of biomass to biochar increases soluble phosphorus levels. This corroborates well with the present study. Increasing the dose by a factor of 1.5 and 2 compared with 5t/ha did not have the same proportional effects in terms of the release of assimilable phosphorus. This could be explained by the fact that biochar applied at rates 1.5 or 2 times higher would release more calcium, which antagonises the release of phosphorus.

Exchangeable bases and their sum were significantly improved in all biochar treatments compared with the unamended control. This improvement is thought to be due to the nutrient inputs from the organic amendment, biochar in the present study, which releases a certain quantity of chemical elements to the soil [37,38]. The better behaviour observed in treatment 3B could be explained by the quantity applied to the soil, which would improve soil quality by releasing sufficient chemical elements [37,38] compared with the control. These results are in line with those obtained by [39], who found that 10 t/ha of organic fertiliser gave better results than 5 t/ha on soil chemical properties.

CEC was significantly improved in the different treatments. It should be noted that this parameter is closely linked to soil colloids (clay and soil organic matter). In this case, although OM content is not significantly correlated with CEC, the latter is linked to organic matter. Furthermore, some authors have highlighted the link between the application of organic matter and CEC [40,41]. In the present study, this increase in CEC would be closely linked to the organic matter in the biochar.

5. CONCLUSION

This study shows that the soil used in the incubation trials is sandy-loam, weakly acidic and low in bases and assimilable phosphorus. The biochar used as an amendment has a very basic pH and very high levels of bases and assimilable phosphorus. The use of biochar incubated in the soil had a positive effect on improving pH, phosphorus, bases and CEC compared with the control. The kinetic study of the different doses over the trial period did not give satisfactory results overall compared with the control. Thus, whatever the duration, treatment 3B corresponding to 10t/ha released more chemical elements than the other treatments, all compared to the control without amendment.

Definitions, Acronyms, Abbreviations

1B: Treatment at 5 t/ha of biochar

2B: Treatment at7.5 t/ha of biochar

3B: Treatment at 10 t/ha of biochar

Ca : Calcium

CEC : Cationic Exchange Capacity

CNAR : National Research Support Centre

DREM : Water Resources and Meteorology Division

FASA : Faculty of Agronomy and Agriculture Sciences

ITRAD : Chadian Institute of Agronomic Research for the Development

K : Potassium

Mg : Magnesium

Na : Sodium

P ass : assimilable Phosphorus

SBE : Sum of Exchangeable Bases

V : Saturation rate

REFERENCES

1. Kasongo LME, Mwamba MT, Tshipoya MP, Mukalay MJ, Useni SY, Mazinga KM, Nyembo KL. Réponse de la culture de soja (*Glycine max L.* (Merril) à l'apport des biomasses vertes de *Tithonia diversifolia* (Hemsley) A. Gray comme fumure organique sur un Ferralsol à Lubumbashi, R.D. Congo. Journal of Applied Biosciences. 2013 ; 63 : 4727-4735.
2. Bahouro A, Djondang K and Nguetnkam JP. Evaluation of the effect of ploughing (animal traction) and direct seeding on the susceptibility to erosion of vertisols in Lere by the analytical method, southwestern Chad. Rev. Ivoir. Sci. Technol. 2022 ; 39 : 234-249. ISSN 1813-3290, http://www.revist.ci.
3. Basga Simon Djakba and Nguetnkam Jean Pierre. Fertilizing Effect of Swelling Clay Materials on the Growth and Yield of Bean "*Phaseolus vulgaris*" on the Sandy Ferruginous Soils from Mafa Tcheboa (North Cameroon, Central Africa); IJPSS, 5(1): 10-24, 2015; Article no. IJPSS. 2015. 056. DOI: 10.9734/IJPSS/2015/13180
4. Sanchez PA. Soil fertility and hunger in Africa. Science. 2002 ; 295 : 2019-2020.

5. Naitormbaide M, Lompo F, Gnankambary Z, Ouandaogo N et Sedogo MP. Les pratiques culturales traditionnelles appauvrissent les sols en zone des savanes du Tchad. Int. J. Biol. Chem. Sci. 2010 ; 4:871-881, ISSN 1991-8631.
6. Useni SY, Chukiyabo KM, Tshomba KJ, Muyambo ME, Kapalanga KP, Ntumba NF, Kasangij A-KP, Kyungu KA, Baboy LL, Nyembo KL, Mpundu MM. Utilisation des déchets humains recyclés pour l'augmentation de la production du maïs (*Zea mays L.*) sur un ferralsol du sud-est de la RD Congo. Journal of Applied Biosciences. 2013 ; 66:5070-5081.
7. Tahir DM, Naitormbaide M, Daoud MB, Nadjam D. Amélioration de la productivité du maïs (*Zea mays L.*) par un apport optimal de fumures organique et minérale en zone soudanienne du Tchad : cas de Bébédjia. Revue Scientifique du Tchad. 2021 ; Serie B : 70-77 2021. ISSN 1017 – 2769.
8. Gove A. Evaluation de l'effet fertilisant des pyroclastites basaltiques du lac Tison et des trachytes de Béka sur les sols de Marza-NGaoundéré. Mémoire de Master, Université de N'Gaoundéré. Cameroun.2015 ; 123.
9. Weber J, Karczewska A, Drozd J, Lieznar M, Lieznar S, Jamroz E, Kocowiez A. Agricultural and ecological aspects of sandy soil as affected by the application of municipal solid waste composts. Soil Biol. Bioch. 2007 ; 39: 1294-1302.
10. Tchabi VI, Azocli D et Biaoue GD. Effet de différentes doses de bouse de vache sur le rendement de la laitue (*Lactuca sativa L.*) à Tchatchou au Bénin. Int. J. Biol. Chem. Sci.2012 ; 6(6) : 5078-5084. DOI : http://dx.doi.org/10.4314/ijbcs.v6i6.26
11. Khalid AA, Tuffour HO, Bonsu B, Mensah PQ. Effects of Poultry Manure and NPK Fertilizer on Physical Properties of a Sandy Soil in Ghana. IJSRAS. 2014 ; 1:1-5. DOI : http://dx.doi.org/10.12983/ijsras-2014-p0001-0005.
12. Biaou ODB, Saidou A, Bachabi F-X, Padonou GE et Balogoun I. Effet de l'apport de différents types d'engrais organiques sur la fertilité du sol et la production de la carotte (*Daucus carota L.*) sur sol ferralitique au sud Bénin. Int. J. Biol. Chem. Sci. 2017 ; 11(5) : 2315-2326. DOI : https://dx.doi.org/10.4314/ijbcs.v11i5.29
13. Sikuzani YU, Ilunga GM, Mulembo TM, Katombe BN, Lwalaba JLW, Lukangila MAB, Lubobo AK, Longanza LB. Amélioration de la qualité des sols acides de Lubumbashi (Katanga, RD Congo) par l'application de différents niveaux de compost de fumiers de poules. . Appl. Biosci. 2014 ; 77 : 6523-6533. DOI : http://dx.doi.org/10.4314/jab.v77i1.3
14. Siene LAC, Doumbouya M, Traore MS, Conde M, N'Guettia TVF et Kone M. Effet de quatre types de fertilisants sur la croissance et la productivité de deux génotypes de maïs (*Zea mays L.*) en cas d'un semis tardif à Korhogo au Centre-Nord de la Côte d'Ivoire. Int. J. Biol. Chem. Sci. 2020 ; 14 (1) : 55-68. DOI : https://dx.doi.org/10.4314/ijbcs.v14i1.6
15. Aubreville A. La végétation du Tchad, ses rapports avec les sols, variations paléobotaniques au quaternaire. O.R.S.T.O.M, Fort-Lamy. 1950 ; 61.
16. Pias J. Les formations sédimentaires tertiaires et quaternaires de la cuvette tchadienne et les sols qui en dérivent, les Mémoires d'ORSTOM. Paris.1970 ; 407.
17. Direction de Ressources en Eaux et de Météorologie. DREM. République du Tchad. 2022.
18. Salzabo D. Ensablement de la plaine fluvio-lacustre de Kah-bi (Sud-ouest du Tchad). Mémoire de master, Université de N'Gaoundéré. Cameroun. 2013 ; 160.
19. Grondard. La végétation forestière au Tchad. Bois et forêts des Tropiques. 1964; 93:15-34.
20. Centre National d'Appui à la Recherche. CNAR (Actuel Centre National de Recherche pour le Développement, CNRD). Carte de végétation du Tchad à l'échelle 1/1000000. République du Tchad. 2015.
21. Bahouro Arka, Nadjiam Djirabaye, Djondang Koye, Adoulko Dalil, Basga Simon, Abderamane Hamit and Nguetnkam Jean Pierre. Determination of optimal doses and periods of biochar and compost application on maize productivity in the sudanian zone of Chad. Int. J. Biol. Chem. Sci. 2023 ; 17(3): 1237-1252. DOI : https://dx. doi.org/10.4314/ijbcs.v17i3.37
22. Pias J. Soil map of Chad at scale 1/1000000. 1964.
23. Cheverry C and Fromaget M. Soil reconnaissance map at 1/200000 of the Republic of Chad. O.R.S.T.O.M. Fort Lamy. Explanatory Note No. 40, 1970; 88.
24.Gerard G. Geological map of French Equatorial Africa at 1/2,000. 1958.
25. Pauwels J.M., Van Ranst E., Verloo M. and Mvondo Zé A. (1992). Manual of pedology laboratory: Methods of Analysis of Soils and Plants, Equipment, Management of Stocks of Glassware and Chemical Products. Agricultural publications-28, 1992, 166 p.
26. Djetoguem S. Mapping and evaluation of the agronomic potential of Pala soils, southwestern Chad. Master's thesis, University of Dschang. Cameroon. 2015 ; 69.
27. Yerima Yaya Alim Ahmadou, Basga Simon Djakba and Nguetnkam Jean Pierre (2023). Effect of biochar and rice husk powder on maize (*Zea mays*) productivity and soils in northern Cameroon. AFRIMED AJ-Al Awamia (139). 2023. p. 85-104.

28. Mounirou MM. Comparative effect of fertilization based on biochar, organic fertilizer and chemical fertilizer on the mineral elements and the production of onion (*Allium cepa L.*). European Scientific Journal, ESJ. 2022; 18 (24): 47-67. https://doi.org/10.19044/esj.2022.v18n24p47

29. Mayola MM, Leyoly J, and Komanda JA. Effect of the application of biochar and Acacia mangium litter on the cultivation of corn in Alley cropping on the Batéké plateau / RDC.2017; 897-907. ISSN 2028-9324 Vol. 19 No. 4.

30. Lele NB. Potential for improving the fertility of sandy and acid soils in Kinshasa (DRC) through the use of charcoal (biochar), plant biomass and mineral fertilizers. Doctoral thesis, Regional Postgraduate School for Integrated Planning and Management of Tropical Forests and Territories, ÉRAIFT. 2016; 196.

31. Guangming H, Jun M, Weiming Z, and Wenfu C. Effect of biochar on microorganisms quantity and soil physicochemical property in rhizosphere of spinach (*Spinacia oleracea L.*). Applied Mechanics and Materials Vols. 295-298. 2013; 210-219. doi:10.4028/www.scientific.net/AMM.295-298.210.

32. Djousse Kanouo Boris Merlain (2017). Production and use of biochar for the amendment of tropical leached red soils. Doctoral thesis, Laval University, Quebec, Canada. 118 pages.

33. Dali Adoulko, Simon Djagba Basga, Rigobert Tchameni, and Jean Pierre Nguetnkam. The Influence of Basalt Powder on the Physicochemical Properties of Impoverished Oxisoils from Ngaoundéré (Adamawa-Cameroon). International Journal of Plant & Soil Science, 33(24): 307-315, 2021; Article no.IJPSS.78726. ISSN: 2320-7035. DOI: 10.9734/IJPSS/2021/v33i2430782

34. Zhang W., Niu J., Morales VL., Chen X., Hay AG., Lehmann J. and Steenhuis TS. 2010. Transport and retention of biochar particles in porous media: effect of pH, ionic strength, and particle size. Ecohydrology, 3: 497-508.

35. Wang L, Xue C, Nie X, Liu Y, Chen F. Effects of biochar application on soil potassium dynamics and cropuptake. J. Plant Nutr. Soil Sci. 2018; 181: 635-643.

36. Kamman CI, Linsel S, Gossling JW, Koyro HW. Influence of biochar on drought tolerance of chenopodium quinoa will and on soil-plant relations. Plant and Soil. 2011; 195-210.

37. Diallo MD. Effect of litter quality of some Sahelian plant species on nitrogen mineralization. Doctoral thesis in plant biology. Cheikh Anta Diop University of Dakar. Senegal.2005; 168.

38. Maman N and Mason S. Poultry manure and inorganic fertilizer to improve pearl millet yield in Niger. Afr. J. Plant Sci., 2013; 7(5): 162-169.

39. Diatité B, Diallo MD, Goalbaye T, Diédhiou S, Diallo A, Talla R, Diop A and Guissé A. Effect of the application of different doses of organic fertilizers on the growth and yield of tomato (*Solanum lycopersicum L* .) under semi-controlled conditions. Journal of Animal & Plant Sciences (J. Anim. Plant. Sci. ISSN 2071-7024).2020; Flight. 44 (1): 7553-7566 https://doi.org/10.35759/JAnmPlSci.v44-1.2.

40. Ruganzu V. Potential for improving acid soil fertility by adding fresh natural plant biomass combined with travertine in Rwanda. Doctoral thesis, University of Liège-Gembloux Agro-Bio Tech/Belgium. 2009. 215p.

41. Schulz H., Dunst G. and Glaser B., 2013. Positive effects of composted biochar on plant growth and soil fertility. Agronomy for Sustainable Development. 33(4): 817-827