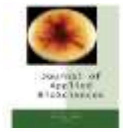


Journal of Applied Biosciences 200: 21113 - 21124
ISSN 1997-5902

Contribution of biochar in maintaining the productivity of sandy soils after *Acacia sp* plantations under maize (*Zea mays*) cultivation at Ntsio in DRC.

Jeancy Ntuka Luta[1], Pierre Clinquart[2], Chançard Kifu[2], Guelord Isulu[2], Irène Kibal[1], Alasca Ekuya[1], François Kabambi[1], Yves-Dady Botula[1], Paul Mafuka[1].
[1] Soil Sciences Research Center (CReSSol), University of Kinshasa, Faculty of Agricultural Sciences and Environment, BP 117 Kinshasa XI (DRC).
[2] Project agroforestry Ntsio, Fondation Hanns Seidel DR Congo .
Corresponding author: *jeancyntuka@gmail.com*

Submission 26th June 2024. Published online at https://www.m.elewa.org/Journals/ on 30th September 2024.
https://doi.org/10.35759/JABs.200.1

ABSTRACT
Objective: The aim of this study was to evaluate the potential of biochar in maintaining the productivity of sandy soils at the Ntsio site after planting *Acacia sp*.
Methodology and Results: The experimental design was a randomized complete block design with 3 treatments and three replications. Each experimental plot measured 50mX20m, separated each one by a distance of 5 m. The treatments were, respectively, T0: Conventional practice (control), T1: Plot with traditional carbonization ovens, T2: Plot with traditional carbonization ovens + one tonne of biochar ploughed in (equivalent to 10tonnes/ha). The experiment was carried out on an acidic soil with a pH of *4.8*. Carbon and nitrogen contents were *3.45 %* and *0.22 ppm* respectively. The average CEC value was *2.08-meq/100 soil*. Maize was used as a testing material. It appeared that during the first growing season the results were better than during the second one for all the parameters studied. However, in the second growing season, the biochar treatment (T1 and T2) produced maize plants with an average height statistically higher than the control. In the first growing season, the biochar-amended treatments produced higher yields, in contrast to the control soil. In the second season, yields were low except in the biochar amended treatment. The greatest decreases in yields were observed for T0 and T1 with a decrease at 67% and 68% respectively. However, On the other hand, in the plot where biochar was incorporated, the yield decrease was 20%.
Conclusion and application of results: The results of this study show that the incorporation of biochar into sandy soils is essential for improving maize yields in the *Acacia sp* agroforestry system. The application of 10 t/ha^{-1} biochar in sandy soils has a positive effect on improving the following sandy soil properties: pH, carbon, phosphorus and CEC, compared to the control soil. The use of biochar in the *Acacia sp* based agroforestry system developed in DR Congo represent an opportunity to improve the productivity of sandy soils, to settle local farmers and persuade them to stop cutting forest trees for agricultural activities.
Keywords: soil fertility, agroforestry, maize, biochar.

RÉSUMÉ

Objectif **:** Cette étude avait pour objectif d'évaluer le potentiel du biochar dans le maintien de la productivité des sols sableux du site de Ntsio après plantation d'*Acacia sp*.

Méthodologie et résultats: Le dispositif expérimental choisi était celui en blocs complets randomisés avec 3 traitements et trois répétitions. Chaque parcelle expérimentale mesurait 50mX20m soit 1000 m^2, séparée de 5 m de distance. Les traitements étaient respectivement, **T0** : Pratique conventionnelle (témoin), **T1** : Parcelle avec des fours à carbonisation traditionnelle, **T2** : Parcelle avec des fours à carbonisation traditionnelle + enfouissement d'une tonne de biochar (équivalent à 10tonnes/ha). Il ressort des résultats sur les paramètres édaphiques que le sol sous étude était acide, avec un pH moyen de 4,8. Les teneurs en carbone et azote étaient respectivement de 3,45 et 0,22 ppm. Concernant la CEC, la valeur moyenne obtenue était de 2,08 méq/100 sols. Concernant la croissance et la production de maïs, il est démontré que pendant la première saison culturale les meilleurs rendements ont été obtenus pour tous les traitements. Cependant, au cours de la deuxième saison culturale, les traitements à base de biochar (T2 et T1) ont donné des plants de maïs avec une hauteur moyenne statistiquement supérieure au témoin. Pendant la première saison culturale, les traitements amendés au biochar ont donné les rendements élevés contrairement au sol témoin. Et à la seconde saison, les rendements ont été faibles sauf sur le traitement sous biochar. Les grandes baisses du rendement ont été observées pour le T0 et T1 respectivement de 67% et de 68%. Par contre, pour la parcelle où le biochar a été incorporé, la diminution n'a été que de 20%.

Conclusion et application des résultats **:** Les résultats de la présente étude ont permis d'affirmer que l'incorporation du biochar s'avère très indispensable pour les sols sableux afin d'améliorer le rendement du maïs dans le système agroforestier à base d'*Acacia sp*. Le taux d'application de 10 t ha-1 de biochar dans les sols sableux a un affect positif sur l'amélioration des propriétés du sol sableux suivantes : le pH, le carbone, le phosphore et la CEC, par rapport au sol témoin. L'utilisation du biochar dans le système agroforestier à base d'*Acacia sp* développé en RD Congo constitue une opportunité pour améliorer la productivité des sols sableux, sédentariser les agriculteurs locaux et amener ces derniers à ne plus déboiser la forêt pour les activités agricoles.

Mots-clés: fertilité des sols, agroforesterie, maïs, biochar.

INTRODUCTION

In the Democratic Republic of Congo (DRC), the rural exodus accelerated by insecurity and civil wars has led to uncontrolled population growth in the country's major cities in general and the city of Kinshasa in particular (Peltier *et al.*,2017). Kouassi *et al.*, (2021) have estimated the annual growth rate of the city of Kinshasa at around 5.1%; by 2030, the city is expected to be home to 24 million people. This increase in the urban population is accompanied by a growing demand for domestic energy (Dubiez *et al.*, 2014). Wood is the main source of this energy for more than 90% of the population in the DRC (Peltier *et al.*, 2017). Around Kinshasa, there are very few forest remnants to provide wood for domestic energy. Savannah is the dominant formation on sandy soils, with a few forest galleries around watercourses that are disappearing (Gond *et al.*, 2016). In developing countries such as DRC, agricultural practices such as slash-and burn farming, short-duration fallowing and the failure to use soil improvers are major factors in the rapid degradation of farmland fertility (Bambara *et al.*,2018; Yaméogo et *al.*, 2019). As a result, the soils organic matter content, easily assimilable nutrients and buffering capacity decrease (Coulibaly *et al.*, 2012; REEB IV, 2017). To solve these issues, research into sustainable land management practices that can improve sandy soil productivity and agricultural production becomes an urgent necessity. However, the natural productivity of these soils is very low (Ntuka *et al.*, 2020). To restore the fertility of sandy soils on the Batéké plateau, farmers resort to natural fallow. As the region's natural flora are dominated by grassy savannahs, soil fertility is only weakly restored with this practice (Lele, 2016). The transition to sustainable agricultural practices is becoming imperative, and this involves technologies adapted to local requirements and within the reach of farmers, who represent a sector employing the largest number of workers across the country (Nsombo et *al.*, 2016). One such technology would be the introduction of agroforestry, which is currently widespread in tropical and semi-arid zones (Kasongo *et al.*, 2009; Nair and Garrity, 2012). This practice improves both soil fertility and productivity, essentially by increasing the availability of nutrients to crops (Jose, 2009). It is in this context of duplicating agroforestry projects based on the model and experience of the Mampu Agroforestry Center that the Ntsio project has been set up in the Batéké Plateau. It aims to improve soil productivity by introducing fast-growing species such as *Acacia sp*, and to give local producers access to more land that is fertile. Furthermore, long-term fallow farming practices in the Batéké Plateau have shown that agroforestry alone has not been able to guarantee the sustainability of agricultural production on the same land (Mungyeko *et al.*, 2017). Following the poor contribution of *Acacia sp*-based fallow to restoring the fertility of these soils, it is required to explore alternative possibilities. This led to the interest in testing the effect of *Acacia sp* biochar on maintaining soil fertility and increasing crop yields in an agroforestry system on sandy soil. Studies carried out at the Mampu Agroforestry Centre by Dubiez *et al*, (2014), Peltier *et al.*, (2017) raised certain uncertainties regarding the maintenance of soil fertility in the agroforestry system after *Acacia sp* fellow. At the end of these studies, it was recommended to set up traditional ovens in the fields on the one hand, and to incorporate some of the biochar produced in the fields as a whole to return the nutrients assimilated by the plants to the soil on the other. This practice could be one of the innovative solutions for maintaining soil productivity in this system. With this in mind, the present study was initiated to evaluate the recommendations made by Dubiez *et al.*, (2014) and Peltier *et al.*, (2017) as reported above. The aim is to assess the potential of biochar in maintaining the productivity of Ntsio sandy soils after planting *Acacia sp* and in increasing maize yield.

MATERIALS AND METHODS

Experimental site: The present study was carried out at the Ntsio agroforestry center on the Batéké plateau in the city-province of Kinshasa in DRC. This plateau, which covers an area of over 9,000 km^2, has a monotonous relief dotted with depressions and deep valleys. The average altitude of the Ntsio site is around 650 m, and its geographical coordinates are 4°46'85.4" South and 16°51'62.5" East. An *Acacia sp* plantation covering an area of 5,500 ha is located on this site. The climate of the study area is tropical, hot and humid, with 1400 mm of rainfall per year. The average annual temperature is 25°C. Soils of the Ntsio agroforestry center are sandy, acidic and chemically poor; the clay content is below 20% (Proces *et al.*, 2017). They are Arenosols, characterized by low organic matter content, low cation exchange capacity (CEC) and low water retention capacity. The vegetation of the Ntsio agroforestry center alternates between savannahs and gallery forests in the valleys with steep slopes. This vegetation is dominated by grassy savannahs with *Digitaria longiflora* and *Hyparrhenia diplandra* and some shrubby species with *Hymenocardia acida, Crossopteryx febrifuga*, *Bridelia ferruginea* (Peltier *et al.*, 2010).

Map of the Ntsio agroforestry center

Materials: Maize seed of the local yellow variety (Samaru) was used to test the effect of treatments. Biochar is the amendment used in this study. It was made from 7-year-old *Acacia sp* wood in an earthen kiln using the traditional process. This process is classified as conventional slow pyrolysis at temperatures not exceeding 350°C to 400°C (Chidumayo, 1994).

Methodology: The experimental set-up chosen was that of randomized complete blocks with 3 treatments and three repetitions.

Soil analysis: Soil samples from each treatment were taken before and after experimentation. They were air-dried in the laboratory to determine the following parameters: pH, CEC, nitrogen, organic carbon, available phosphorus and basic cations. Soil pH was measured at a ratio of 1:2.5 (weight/volume). CEC was determined using an extract of ammonium acetate solution at pH 7 and a soil-solution ratio of 1:4. Soil organic carbon was determined by the Walkley and Black method (GLOSOLAN, 2019), which involves oxidizing organic carbon with potassium dichromate ($K_2Cr_2O_7$) in a concentrated sulfuric acid (H_2SO_4) solution (Van Ranst *et al.*, 1999). Soil organic matter content was calculated by multiplying organic carbon content by a factor of 1.724; the conversion factor is because organic matter contains an average of 58% organic carbon (GLOSOLAN, 2019). Phosphorus was determined using an atomic absorption spectrometer by the Olsen method in a 1:10 ratio (soil/Bray II extraction solution). Nitrogen was determined using the Kjeldahl method as described by GLOSOLAN (2019).

Statistical analysis: Analysis of variance at the 5% probability level, using SPSS software, was used. Then, a comparison of means test to detect differences between treatments was performed.

RESULTS AND DISCUSSION.

Physico-chemical properties of the soil: In order to determine the influence of Acacia sp on improving the fertility of Ntsio's sandy soils, numerous edaphic parameters were taken into account at the starting point of the experiment.

Table 1: Physico-chemical parameters of soils under *Acacia sp*.

	Average ± Standard deviation
Soil Parameters	Sol under Acacias sp.
pH-(water)	4,8±0,07
C.O (%)	3,45±0,7
N (%)	0,22±0,09
P.ass (ppm)	36,35±3,8
Ca^{2+} (meq/100 of the soil)	0,41±0,04
Mg^{2+} (meq/100 of the soil)	0,12±0,02
K^{+} (meq/100 of the soil)	0,04±0,01
CEC (meq/100 of the soil)	2,62±1,79

The results in Table 1 show that the *Acacia sp* plantations had an influence on some physico-chemical soil parameters through the litter and roots. Kabore *et al.,* (2020) found that woody species such as *Gliricidia sepium and Albizia lebbeck* improved soil fertility in Burkina Faso. Based on the interpretation standards proposed by Landon in 1991, the pH-water value obtained is, 4.8, (Table 1) which is below 5.5 considered as the threshold, therefore soils of the experimental site can be qualified as strongly acidic. At values below threshold of 5.5, the author stipulates that biochemical reactions occur in the soil that may hinder plant growth. Similar results were found when assessing the effect of *Acacia sp* plantations on primary soil macronutrients on the Batéké Plateau by Nsombo *et al.,* (2016). Results of this study showed that the carbon and nitrogen contents of the experimental site are the same as those found by some authors. Indeed, Bisiaux *et al.,* 2013, Dubiez *et al.,* 2018, Kachaka 2020 found similar results at the Batéké plateau. Similar results were also found by Ndiaye *et al.,* 2012, Ouoba *et al.,* 2018, Kabore et *al.,* 2020 under other legume species such as *Cordyla pinnata*, *Maranthes polyandra*. Gnahoua *et al.,* (2013) also showed that the litter of leguminous species such as *Acacia auriculiformis, Acacia mangium, Albizia lebbeck* and *Leucaena leucocephala* releases sufficient nitrogen and carbon into the soil. Regarding basic cations, no major improvement was observed in their concentrations in the soils following the establishment of *Acacia sp*. These results can be justified in the sense that *Acacia sp* were installed in sandy soils and these effects could be limited due to the low nutrient retention capacity of these soils. Regarding CEC, the values obtained are similar to those presented by Kachaka (2020); the latter emphasized that agroforestry fallow brings a significant amount of organic matter into the soil, which influences CEC. Zhang *et al.,* (2012) had pointed out that Acacia sp have the capacity to fix atmospheric nitrogen symbiotically, and that they release this element into the soil during the decomposition of nodules, roots and dead leaves, thus increasing the soil's organic matter content. This organic matter acts as a binding agent, increasing soil CEC by providing cation exchange sites to retain essential nutrients such as ammonium (NH_4^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+) ions.

Maize growth parameters

- ***Average plant height:*** To evaluate the effects of the amendments on maize plant height (cm), data were collected on day 60 after sowing for both growing seasons.

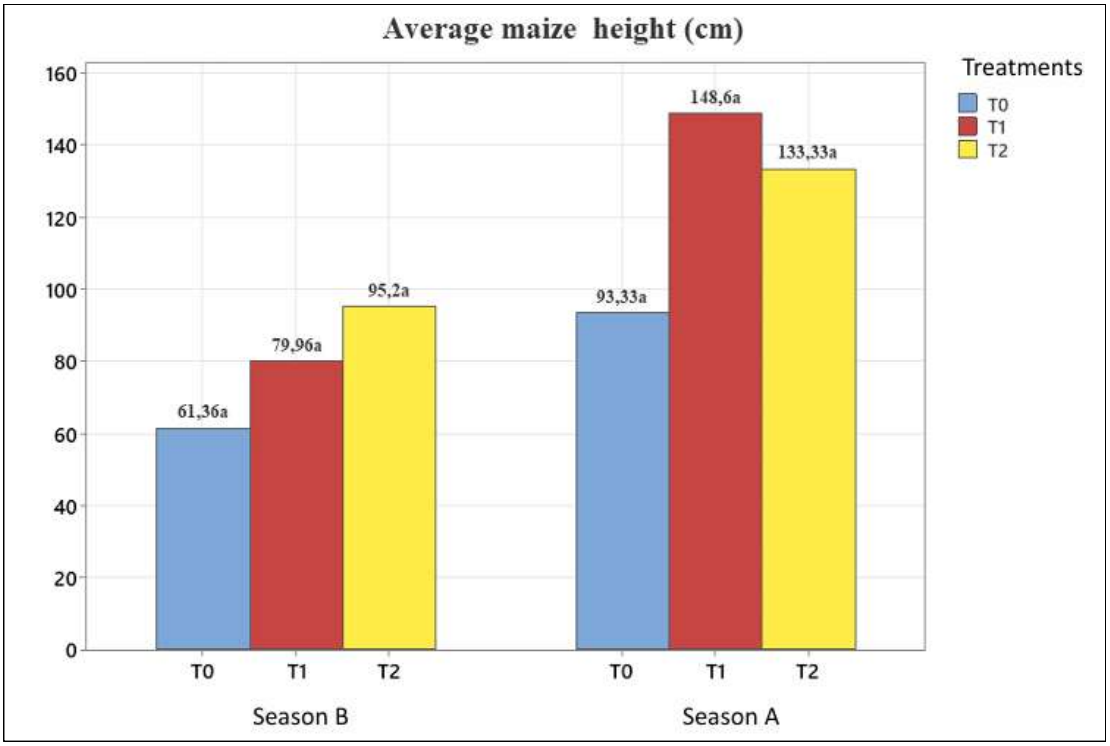
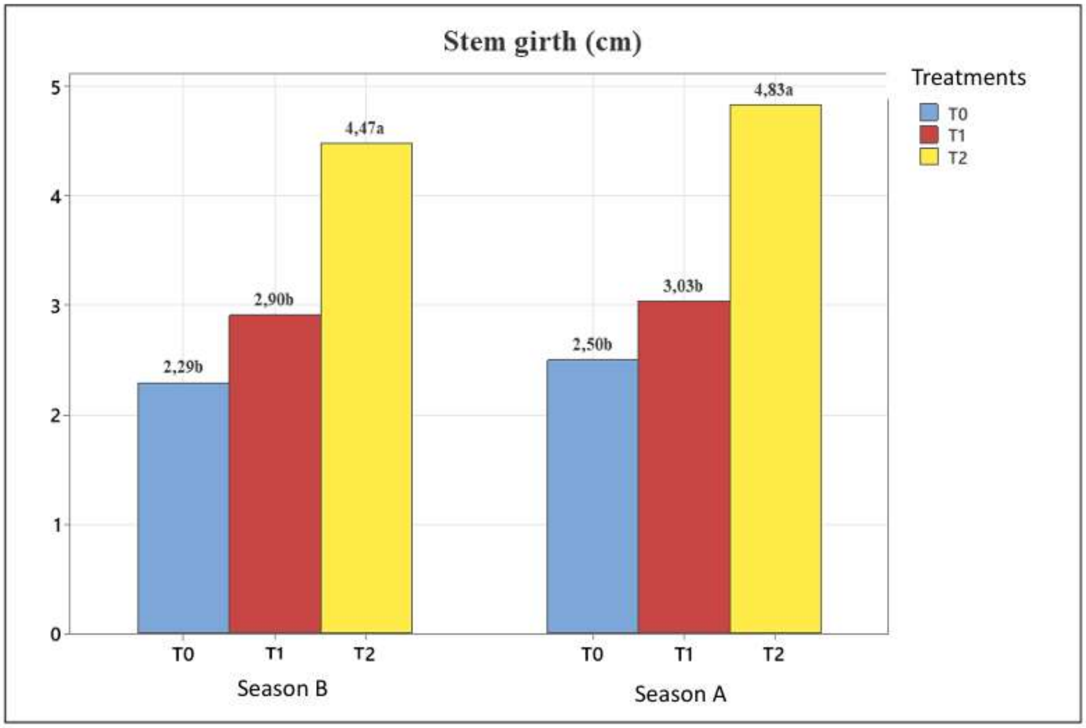


Figure 2: Average maize height over the two growing seasons (cm).
Histograms with the same letters at the top are not significantly different at the 5% level.
Legend: ***T: treatment. T0:*** *Plots with conventional practices (control), T1: Plots with traditional carbonization ovens, T2: Plots with traditional carbonization ovens + burying of one tonne of biochar (equivalent to 10tonnes/ha).*

The height data in Figure 2 for the first growing season show no significant differences between treatments. However, in the second growing season, although plant heights were more stable, significant differences appeared. The biochar treatments (T2 and T1) produced maize plants with an average height statistically higher than the control. Low heights were recorded for the treatment corresponding to conventional practices (T0). Similar results were observed by Saba (2023) in Burkina Faso, showing that the addition of biochar to the sandy soil in the Sahel had positive effects on maize growth, and increased maize height by between 17 and 67%. Hesham *et al.*, (2020) also found that incorporating biochar into the field attenuated the negative effect of water stress on wheat height by 2.1%. Results of this study show that the incorporation of biochar into the sandy soil, fallow of *Acacia sp* influences maize plant height over the course of two cropping seasons. Moreover, plant height decreased in the treatment that did not receive the biochar amendment in the second cropping season. In addition, the positive effects of biochar may be due to the increased water-holding capacity of the soil (Ahmed *et al.*,2015) and the slow release of this water into the soil in favour of maize (Khadem *et al.*,2010).

- ***Stem* girth:** Measurements of maize plant stem girth were used to determine the impact of biochar application and oven installation on experimental plots at 60 days after planting for both cropping seasons.



These results show that there is a significant difference (at the 5% threshold) between the treatment (T2) and the others in both cropping seasons. Similar results were also obtained by Lele in 2016. Sihua Yan *et al*, (2022) also found that biochar incorporation mainly affected the stem girth of growing maize plants. The present study confirms the findings of Zheng et *al.*, (2017), Razzaghi et *al.*, (2020) and Guo et *al.*, (2021) who reported that biochar addition to sandy soils had a positive effect on crop growth.

Maize production parameters: The level of maize yield was an important indicator of the influence of biochar application and charcoal ovens on individual plots over the course of two cropping seasons.

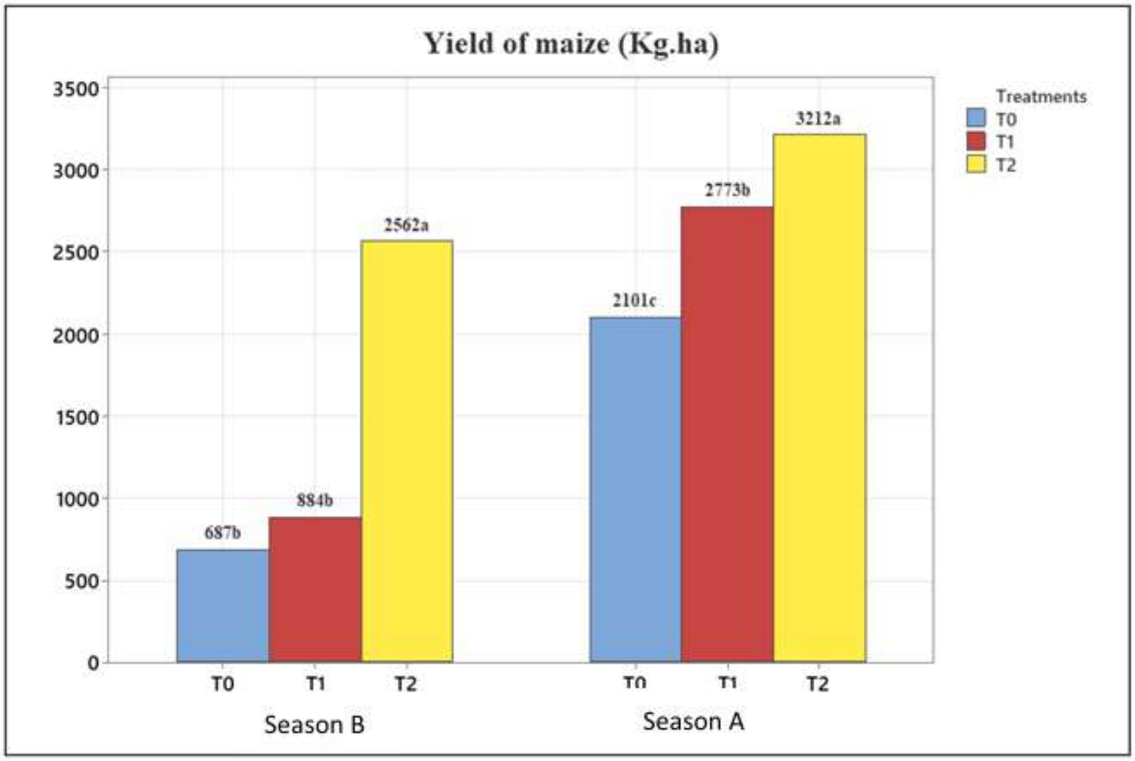


Figure 3: Maize yield over two growing seasons
Legend: ***T: treatment.*** *T0: Plots with conventional practices (control), T1: Plot with traditional carbonization ovens, T2: Plot with traditional carbonization ovens + burial of one tonne of biochar (equivalent to 10tonnes/ha).*

In general, the performance of maize plants under different treatments is a function of the amendments applied. Figure 3 shows that carbonization on the experimental plots positively affected maize grain yield in comparison with the control for the first growing season. During this season, the plots amended with biochar gave yields of 3,212 kg/ha and 2,773 kg/ha for treatments T2 and T1, respectively.In the second season, yields were low, dropping by more than 60% i.e. 67% for T0 and 68% for T1. On the other hand, for the plot where biochar was incorporated, the reduction was only 20%, which is an acceptable level. Similar results on the maize crop of around 6,013 kg/ha were also found by Boris Kanoo *et al.,* (2017) on biochar-amended Ferrasols soil in Cameroon. The yield of the control in the present study agrees with that found by Peltier *et al.*,(2017) on sandy Batéké plateau soil, which amounted to 1,500 kg/ha.

CONCLUSION AND APPLICATION OF RESULTS

The effectiveness of biochar in improving soil fertility, crop productivity, rehabilitating degraded land and mitigating climate change has been the subject of several studies over the last few decades. Its application to improve agricultural soil productivity is not a new phenomenon. The results of this research have ranged from a clear improvement in soil fertility to virtually no difference compared with the control, depending on soil type, crop, biochar type and environment. Furthermore, information from large-scale field trials on the effects of biochar in maintaining the fertility of sandy soils in an agroforestry system is still very limited. For this reason, this trial was initiated on a large area estimated at 1/2 hectare to assess the potential of biochar in maintaining the productivity of

Ntsio sandy soils after planting *Acacia sp* under maize cultivation. A wide range of biochar impacts on soil properties, with particular emphasis on maize crop response, was studied over two cropping seasons. The Plot with traditional carbonization ovens had a positive effect on maize yields compared with the control in the first growing season. During this season, the plots amended with biochar gave yields of 3,212 kg/ha and 2,773 kg/ha for treatments T2 and T1 respectively. These results highlight the importance of building charcoal kilns in plots after *Acacia* felling; the effectiveness of biochar in improving and maintaining maize yields is only apparent when it is buried in plots fallowed with *Acacia sp*. These results suggest that the incorporation of biochar is essential for improving maize yields in the *Acacia sp* agroforestry system on sandy soil. The study also revealed that biochar application rates of 10 t/ ha in sandy soils had a positive impact on pH, carbon, phosphorus and CEC. Furthermore, the use of biochar in the *Acacia sp* agroforestry system developed in DRC would represent an opportunity to improve the productivity of sandy soils in other parts of the country.

ACKNOWLEDGEMENTS

This study was made possible thanks to the financial support of the MITI IDWINI Agroforestry Project - Trees to protect our land (financed by the European Union and implemented by the Hanns Seidel Foundation DRC).

REFERENCES

Bambara D., Bilgo A., Sawadogo J., Gnankambary Z., Thiombiano A., (2018). Évaluation de la diversité et de la qualité de pratiques d'agriculteurs face à la dégradation du milieu biophysique au Burkina Faso. Journal of Applied Biosciences, vol 125(1). 2551-12565. https://doi.org/10.4314/jab.v125i1.5

Bisiaux, F., Diowo, S., Lufungula, S., Wakambo, S., Mafinga, J.-P., Matungulu, P., Lebou, L., Dubiez, E., Dominique, L. et Marien, J.-N. (2013). Réintroduire l'arbre dans le système cultural : succès et difficultés de l'agroforesterie villageoise. In : Quand la ville mange la forêt : Les défis du bois-énergie en Afrique centrale. Marien, J.N., Dubiez, E., Louppe, D., Larzillière, A. Editions. Quae, Versailles, 149-155.

Boris Merlain Djousse Kanouo, Suzanne Edith Allaire, Alison D. Munson (2015). Biochar Improves Maize Nutritional Status and Yield under Two Soil Tillage Modes. International Journal of Science and Research (IJSR) ISSN (Online) : 2319-7064

Chidumayo E.N. (1994.), Effects of wood carbonization on soil and initial development of seedlings in miombo woodland, Zambia, For Ecol Manage, No 70, pp 353- 357 https://doi.org/10.1016/0378-1127(94)90101-5

Coulibaly K., Vall E., Autfray P., Nacro HB. & Sédogo MP., (2012). Effets de la culture permanente coton-maïs sur l'évolution d'indicateurs de fertilité des sols de l'Ouest du Burkina Faso. International Journal of Biological and Chemical Sciences,6, 1069-1080. https://doi.org/10.4314/ijbcs.v6i3.13

Dubiez E., Marien J.N., Bisiaux F., Freycon V., Peroches A., Peltier R., (2014). La durabilité des systèmes agroforestiers à Acacia auriculiformis en Afrique centrale. Notes de perspectives.

Dubiez, E., Freycon, V., Marien, J. N., Peltier, R., & Harmand, J. M. (2018).

Long term impact of Acacia auriculiformis woodlots growing in rotation with cassava and maize on the carbon and nutrient contents of savannah sandy soils in the humid tropics (Democratic Republic of Congo). Agroforestry Systems, 1-12. https://doi.org/10.1007/s10457-018-0222-x

Global Soil Laboratory Network (GLOSOLAN 2019). Standard operating procedure for soil organic carbon Walkley-Black method Titration and colorimetric method et Standard operating procedure for soil nitrogen Kjeldahl method

Gnahoua GM., Oliver R., Nguessan KA. & Balle P. (2013). Production et retombées minérales des litières chez quatre espèces de légumineuses arborées, utilisées en amélioration de jachères, en zone forestière de Côte d'Ivoire. Journal of Applied Biosciences,vol. 72, 5800-5809. https://doi.org/10.4314/jab.v72i1.99665

Gond V., Dubiez E., Boulogne M., Peroches A., Pennec A., Peltier R., (2016). Forest cover and carbon syock change dymanics in the DRC : case of the wood-fuel supply basin of Kinshasa. Bois et forêts des tropiques, 327. https://doi.org/10.19182/bft2016.327.a31293

Guo, L., Bornø, M. L., Niu, W., Liu, F. (2021). Biochar amendment improves shoot biomass of tomato seedlings and sustains water relations and leaf gas exchange rates under different irrigation and nitrogen regimes. *Agric. Water Manage.* 245, 106580. doi: 10.1016/j.agwat.2020.106580

Jose, S., (2009). Agroforestry for ecosystem services and environmental benefits: an overview. Published online: 7 April 2009; Springer Science+Business, pp 1-10. https://doi.org/10.1007/978-90-481-3323-9_1

Kabore W. B, Soulama S, Bambara D, Bembamba M, Hien E (2020). Effet de Albizia lebbeck(L.) Benth. et Gliricidia sepium (Jacq.) Kunth ex Walp. sur les paramètres de fertilité du sol. Journal of Applied Biosciences 156: 16078 – 16086 https://doi.org/10.35759/JABs.156.2

Kachaka Y. E (2020). Effets de l'âge des jachères agroforestières à Acacia auriculiformis sur les sols, les rendements de culture et adoption par les agriculteurs du plateau des Batéké, en République démocratique du Congo. Doctorat en sciences forestières. Université de Laval.

Kasongo, R.K., Van Ranst, E., Verdoodt, A., Kanyankagote, P. Baert, G., (2009). Impact of Acacia auriculiformis on the chemical fertility of sandy soils on the Bateke plateau, D.R. Congo. Soil Use and Management, n° 25, pp 24. https://doi.org/10.1111/j.1475-2743.2008.00188.x

Kouassi Yeboua, Jakkie Cilliers et Stellah Kwasi (2021). Réveiller le géant endormi. Trajectoires de développement de la République démocratique du Congo à l'horizon 2050. Rapport sur l'afrique centrale 18 | février 2021

Landon J.R., 1991. Booker Tropical Soil Manual. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. United states, New York, 474 p.

Lele N.B (2016). Potentiel d'amélioration de la fertilité des sols sableux et acides de Kinshasa (RDC) par l'usage du charbon des bois (biochar), de la biomasse, Lele N.B (2016). Potentiel d'amélioration de la fertilité des sols sableux et acides de Kinshasa (RDC) par l'usage du charbon des bois (biochar), de la biomasse végétale et des engrais minéraux. Thèse de doctorat - ÉRAIFT. Pp 85

Mungyeko M.M., Leyoly J., Aloni K.J (2017). Effet de l'application du biochar et de la litière d'Acacia mangium sur la culture du maïs en Alley cropping au plateau de Batéké / RDC

Nair, P.K.R. et Garrity, D., (2012). Agroforestry: The future of global land use. Advances in agroforstry 9. Springer, 541 p. https://doi.org/10.1007/978-94-007-4676-3

Ndiaye Samba SA., Elhadji F., Tala G., Hank M. & Camire C., (2012). Cordyla pinnata améliore les propriétés du sol et la productivité des cultures. International Journal of Biological and Chemical Science,vol 6, 714-725. https://doi.org/10.4314/ijbcs.v6i2.15

Nsombo M. B., Lumbuenamo S. R., Aloni K.J., Lejoly J., Mafuka M-M.P. (2016). Effet des plantations d'Acacia sp sur les macronutriments primaires des sols sableux d'Ibi village au plateau des Bateke (Kinshasa, République Démocratique du Congo).

Ntuka L J., Ekuya L A., Kibal M I, Mafuka M P (2020). The effects of physico-chemical characteristics of sandy soils amended with biochar, Ricinus and NPK (17-17-17) on the Okra (Abelmoschus esculentus) in Kinshasa (DR Congo). www.m.elewa.org/journals/ https://doi.org/10.35759/JABs.156.3

Ouoba P., Yaméogo JT., Ouédraogo A. et Kouaman S., 2018. Potentialités agroforestières de Maranthes polyandra (Benth .) Prance au sudouest du Burkina Faso. Journal of Applied Biosciences, vol 128, 12920-12931. https://doi.org/10.4314/jab.v128i1.5

Peltier R., Bisiaux F., Dublier E., Marien J.N., Freycon V (2021). Restauration de la productivité des sols tropicaux et méditerranéens.- chapitre 9. Agriculture sur brûlis de la jachère à acacias pp 1-2.

Razzaghi, F., Obour, P. B., Arthur, E. (2020). Does biochar improve soil water retention? a systematic review and meta-analysis. *Geoderma* 361, 114055. doi: 10.1016/j.geoderma.2019.114055

REEB IV., (2017). Quatrieme rapport sur l'état de l'environnement au Burkina Faso. SP/CNDD, Ouagadougou, 271p.

Sihua Yan, Shaoliang Zhang, Pengke Yan and Muhammad Aurangzeib (2022). Efect of biochar application method and amount on the soil quality and maize yield in Mollisols of Northeast China. https://doi.org/10.1007/s42773-022-00180-z.

Van Ranst E., M. Verloo, A. Demeyer, and J.M. Pauwels (1999). Manual for Soils and Fertility Laboratory. Analytical Methods for Soils and Plants. Equipment and Management of Consumables. Faculty of Bioscience engineering. University of Ghent, Belgium. 243 p.

Yaméogo JT., Sanon Z., Baggnian I., Somda I., Somé AN. et Axelsen JA., (2019). Impact des différents types d'occupation des terres sur la fertilité physique et chimique du sol dans la réserve totale et partielle de Bontioli (Sud-Ouest) du Burkina Faso. Science et technique, Sciences naturelles et appliquées,vol. 38, 33-45

Zhang, H., Luo, Y., Zhou, G., & Zhang, X. (2012). Biochar application to a sandy soil increased maize yield and soil nutrient availability. Journal of Environmental Quality, 41(3), 841-847. doi: 10.2134/jeq2011.0193 https://doi.org/10.2134/jeq2011.0193

Zheng, J., Han, J., Liu, Z., Xia, W., Zhang, X., Li, L., et al. (2017). Biochar compound fertilizer increases nitrogen productivity and economic benefits but decreases carbon emission of maize production. *Agriculture Ecosyst. Environ.* 241, 70–78. doi:10.1016/j.agee.2017.02.034