Vol. 19(2), pp. 178-188, February, 2023
DOI: 10.5897/AJAR2022.15925
Article Number: 2E1069E70358
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Effect of manure-based biochar amendment on soil chemical properties, total enzymic activities and tomato growth performance in acidic soil under controlled conditions

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Received 4 January, 2022; Accepted 27 April, 2022

The aim of this study is to evaluate the effect of biochar on tomato production under controlled conditions. Trials were installed using a complete randomized block design (CRD) with 5 replications of 4 treatments: T0 (0%); T1 (8%); T2 (12%) and T3 (16%). During plant growth, parameters including height, diameter, number of leaves, number of fruits and plant biomass were collected. Plants obtained from pot that received biochar (T1, T2 and T3) were higher than plant without biochar application (T0). The average value of tomato fruits per treatment indicated that plants from treatment T1 displayed a greater number of fruit per plant with an average of 12±2; whereas plants in control treatment, T0 did not have fruit. Plants from treatments T2 and T3 showed a number of fruit between control and T1. Soil chemical analysis indicated that exchangeable cation, CEC, pH, SOM, total nitrogen and C/N ratio were higher than in the initial soil. Regarding microbial activity, various treatments did not have a significant effect on soil enzymic activity. The recovery of waste as a source of organic materials is a practice to be encouraged in urban horticulture and in open field to restore soil fertility.

Key words: Biochar, soil quality, tomato, yield.

INTRODUCTION

Severe soil fertility depletion and declining agricultural productivity due to a reduction of soil organic matter (SOM) and nutrient imbalances are major constraints in most tropical agricultural soils (Lal, 2015). Shrinking land area per capita and declining soil quality have led to a constant increase in the rate of inorganic fertilizer usage from year to year to maintain or enhance agricultural productivity (Srivastava, 2009). However, the application of chemical fertilizer alone is not a sustainable solution for improving soil fertility and maintaining yield increases in tropical regions. Futhermore, it has been widely recognized that application of excessive inorganic

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fertilizer, especially nitrogen and phosphorus, may cause soil deterioration and other environmental problems. This is because more rapid organic matter mineralization induces a decrease in soils' carbon stock (Liu et al., 2010). This is in contrast with the international initiative of "4 per 1000". This initiative is to demonstrate that agriculture, and in particular agricultural soils can play a crucial role in carbon storage.

According to this initiative, an annual growth rate of 0.4% in the soil carbon stocks in the first 30-40 cm of soil would significantly reduce the CO_2 concentration in the atmosphere related to human activities. In this context of climate change and land degradation, the growing global demand for food means that agricultural systems in tropical zone must be both more productive and resilient (FAO, 2004). Hence, innovative tools are required to deal with these complex challenges, which have fueled interest in biochar as a potential soil amendment to improve soil quality and crop productivity (Lehmann et al., 2006).

Biochar is a porous, carbon-rich material produced by pyrolysis of organic matter at temperatures ranging from 300 ºC and 1000 ºC without oxygen or limited environment in oxygen (Verheijen et al., 2010). In addition, biochar once incorporated into the soil, as an amendment, could alter the properties of soil by improving its physical, chemical and biological properties through the supply of organic matter, soil structure improvement and nutrients and water retention (Laghari et al., 2016). It would also stimulate the activity of microorganisms, symbioses and mycorrhizae in soils (Steinbeiss et al., 2009). Application of biochar to agricultural soil would promote enzymatic activity, microorganism and biofilm proliferation due to its large specific surface area and high density of macroscopic and microscopic pores (Lehmann et al., 2011). Its ability to adsorb soluble organic matter, gases and inorganic nutrients makes it an ideal habitat for microorganisms, particularly bacteria (Thies and Rillig, 2009). Therefore, the application of biochar in a field would improve agricultural performance while decreasing chemical fertilizer input and fight against climate change (Zanutel, 2019). The use of biochar in organic agriculture appears as an alternative for better management of organic matter and fertility of tropical soils. Nevertheless, its impact on soil properties would depend on several factors including the nature of the pyrolysed biomass and the type of soil where it is applied (Jha et al., 2010).

This study helps to understand the effect of biochar on soil properties in organic tomato production in tropical areas. The quantities of agricultural residues in West Africa are constantly increasing during the last decade. For example, poultry farming in Côte d'Ivoire has been expanding in recent years with an estimated poultry production of 40,000 tons per year now compared to 18,000 tons per year in 2011 (CIRAD, 2017). This production has led to an increase in poultry waste of which just 2% is recycled as manure in agriculture, especially in vegetable production. The release of manure into the natural ecosystems can lead to nitrate and phosphate pollution of surface water and groundwater. This study was therefore initiated to evaluate the effect of poultry manure based biochar on soil quality and productivity of tomato under controlled conditions. The demand for tomatoe in Côte d'Ivoire is quite higher compared to local production ranging from 22,000 and 35,000 $t.ha^{-1}.yr^{-1}$ (Sangaré et al., 2009). More specifically, this study aims to determine the effect of biochar on the availability of nutrients in the soil, microbial activity of the soil and growth and yield of tomato.

MATERIALS AND METHODS

Biochar production

Biochar used in this study was produced from a mixture of guinea fowl (*Agelastes* sp) manures and dry straw in a traditional pyrolysis oven. Approximately 40 kg of dried guinea fowl manures and 400 g of dry straw were placed layer by layer at the rate of 10 kg of manure for every 100 g dry straw. It was burnt without oxygen in traditional oven to produce 15 kg of biochar. Pyrolysis was carried out at a temperature of 300ºC for 48 h.

Experimental setup and growth conditions

A greenhouse experiment was performed for three months in a greenhouse of Felix Houphouet-Boigny University, located in Bingerville (Côte d'Ivoire). The experiment was carried out with commercial plastic pots of 2.5 L (Ø 17 cm, height 20 cm, surface area 0.40 m^2). About 2.0 kg of top soil was sieved in 2 mm sieve and mixed to coarse elements (1.0kg) to obtain a substrate of 3.0 kg pot^{-1}. Three doses of biochar were applied to substrates as treatments and compared with an untreated control soil (T0). The various biochar doses are 0, 8, 12 and 16% respectively for T0, T1, T2 and T3. The experiment was designed in a completely randomized block design (CRD), with 5 replications. Three untreated seeds of tomato (*Solanum lycopersicum* L., "Petomech V", Semivoire, Côte d'Ivoire) were sown in each pot.

Five days after sowing, thinning was done and the best plant from each pot was kept. Manual irrigation was set two times a day. At 27th day after sowing, five plants (one plant per replication) of each treatment were tagged to carry out all the measurements, every week. The measurements concerned were growth parameters (height, diameter of the stem at the collar and leaf number) and fruits were counted at 65th day after planting. The total biomass was determined at the end of the cultivation (65th day after planting), and after drying the samples in the oven at a temperature of 70ºC for 72 h.

Chemical and microbiological analyses

Approximately 300 g of biochar was taken after a homogeneous grinding before applied on the ground for analyses. Substrates (soils) samples were collected at the end of the trial. About 100g fractions were instantly stored at -12ºC for microbiological analyses. In addition, a second substrate fraction was dried in ambient air until its weight was stable. Then, it was sieved to 2 mm for analyses. The chemical and microbiological analyses are summarized in Table 1. All the chemical analyses were carried out in the Laboratory of the National Polytechnic Institute of Yamoussoukro (Côte d'Ivoire), according to classical laboratory

Table 1. Methods of analysis of the physicochemical and biological parameters of the soil andbiochar used in this study

Soil parameters	Unit	Used Laboratory methods
Total organic carbon (TOC)	mg. kg^{-1}	Modified Springer-Klee wet method[1]
Total nitrogen content		Kjeldahl method[2]
Available phosphorus		Determined by the Bray and Kurtz (Bray II) method[3]
Exchangeable cations	cmol^{+}. kg^{-1}	Extraction with ammonium acetate and analysis with atomic absorption spectrophotometer[4]
Microbiological analysis	-	Determined by hydrolysis of fluorescein diacetate (FDA)[5]

Source: (1) Vitti et al., (2016), (2) Darrell and Lee (1980), (3) Bray and Kurtz (1945), (4) Ciesielski et al., (1997), (5) Gillian and Duncan (2001)

methods. These analyses were carried out on the following parameters: pH, organic carbon, total nitrogen, CEC, exchangeable bases and available phosphorus.

The enzymatic activity was carried out using 1g of frozen soil samples in tube of 50 ml. Then, 10 ml of buffer potassium phosphate (KH_2PO_4) was added to the soil samples. The enzymatic reaction is initiated by adding 100 µl.ml^{-1} of fluorescein diacetate (FDA) ($C_2OH_{12}O_5$ free acid, Sigma Aldrich)) solution to each tube. The tubes were then gently shaken at 40 rpm for 60 min. The supernatant solution was collected by centrifugation at 3000 rpm for 10 mn. FDA hydrolysis was estimated using a 450 nm wavelength spectrophotometer.

Statistical analyses

The data collected were subjected to statistical testing using XLSTAT 2014 software, version 4. An analysis of variance (ANOVA) was used to assess the effects of biochar doses on soil and plants' agromorphological parameters. The comparison of means was made possible by the Dunnett method comparison test of means at 5% probability threshold.

RESULTS AND DISCUSSION

Effect of biochar application on chemical properties and enzymatic activities of soil

Table 2 shows the chemical analysis results of the selected properties of the substrate . The application of biochar significantly improved all soil chemical properties compared to control. The measured pH values of the substrate were very high: 1.77, 2.37 and 3.23 pH unit respectively for treatments T1, T2 and T3 compared to control (T0). The comparison of treatment T1, T2 and T3 indicated that the pH values were not statistically different. As expected, Soil organic matter (SOM) content increased in pot that received biochar compared to control treatment. The highest SOM content was obtained with T2 treatment. Because of this improvement, an increase of total nitrogen content was about 98, 175 and 118% respectively with T1, T2 and T3 treatments compared to control (T0). However, C/N ratio showed similar values between 10.57±1.13 for T2 treatment and 10.66±0.57 for control.

Measured exchangeable cations in the substrate are presented in Figure 1. Calcium appeared as the most abundant cation on the cation exchange complexes. Highly significant differences were observed between all treatments for exchangeable bases. Compared to control, calcium content increased by about 120, 121 and 45% for T1, T2 and T3, respectively. The others' base cations displayed similar content on the exchange complexes. For Mg^{2+}, the contents for treatment T3 (1.21±0.08 cmol^{+}.kg^{-1}), T2 (1.25±0.06 cmol^{+}.kg^{-1}), T1 (1.26±0.10 cmol^{+}.kg^{-1}) remain statistically similar to each other but all are twice higher than T0. The exchangeable K^{+} contents for the treatments T3, T2 and T1, T0 are respectively, 1.40±0.12 cmol^{+}.kg^{-1}, 1.08±0.07 cmol^{+}.kg^{-1} and 1.14±0.10 cmol^{+}.kg^{-1} and are 4 to 5 times greater than control (T0). The difference between T3 and the other treatments (T2 and T1) remained identical.

The biochar applied improves the cation exchange capacity of soil according to different doses. Results showed that CEC values increased from T3 to T1, with increase of 193, 81 and 26%, respectively compared to control.

However, base saturation rate of soils for different biochar applications decreased following the applied biochar dose (Table 3). The levels of available phosphorus in the soil also showed an increase with various biochar doses.

Available P for T1, T2 and T3 treatments compared to control T0 increased by 48, 52 and 8%, respectively. The difference is only significant between T1, T2 and T0.

The total enzymic activities with the different biochar doses are shown in Figure 2. Results show that control and absolute soil displayed higher total enzymatic activities, with significant difference, compared to the soil amended with biochar. Total enzymatic activities of the control and absolute soil were 35, 27 and 52% greater than those of the soil amended with biochar T1, T2 and T3, respectively.

Recent studies have proved that biochar application increases soil chemical properties, although the effects may vary between biochar types/doses and soil types (Gul et al., 2015), similar to compost effect (Gnimassoun et al., 2020; Adugna, 2018; Lanna et al., 2017). The effects on chemical properties of soil can be summarized into two biochar properties. Firstly, it is a nutrient-rich amendment, and some nutrients can be returned to the

Table 2. Selected chemical soil properties of soil and biochar analyses. CEC, S and C/N indicate the cation exchange capacity and soil saturation rate and Carbon/Nitrogen ratio respectively.

	pH	OM	N_{total}	$P_{available}$	CEC	S	C/N
	-		mg.kg^{-1}		cmol^{+}.kg^{-1}	-	-
T0	5.37±0.64	4.87±0.33	0.27±0.03	38.00±5.29	9.33±4.51	10.66±5.45	10.66±0.57
T1	7.13±0.06	9.62±0.40	0.53±0.03	56.33±11.06	11.80±1.59	31.22±0.87	10.63±0.18
T2	7.73±0.12	13.18±0.67	0.73±0.12	57.67±8.02	16.93±4.23	22.95±7.08	10.57±1.13
T3	7.60±0.20	10.58±0.96	0.58±0.06	41.00±2.00	27.33±2.40	15.45±1.42	10.61±0.37
Biochar	8.70±0.13	63.54±2.90	1.55±0.03	0.39±0.03	84.93±11.24	0.06±0.01	23.83±2.28

Source: Author own data and calculations

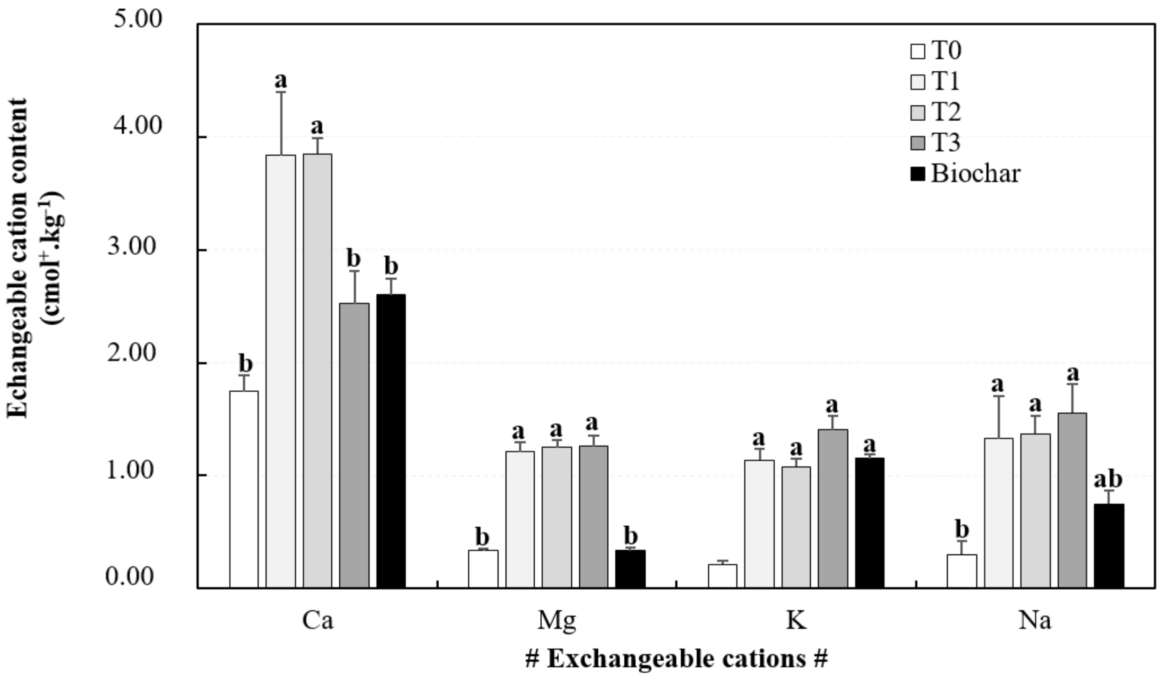

Figure 1. Base cation content in soil amended with biochar (T0: 0%), (T1: 8%), (T2 :12%) and (T3 : 16%). Means with the same letter are not significantly different from each other (P>0.05 ANOVA followed by Dunnett comparison test). Error lines represent ± standard deviation of the mean.
Source: Author own data

soil (Glaser et al., 2002).

Secondly, it is a reducer of nutrient losses from soil due to its high adsorption capacity (Gul et al., 2015). The quality and quantity of biochar depend on its production process. The temperature adopted for biochar pyrolysis (Lehmann, 2007; Downie et al., 2009; Noor et al., 2019) could change carbon and nitrogen concentrations in biochar and surface adsorption properties (Yuan et al., 2011). Zhao et al. (2018) suggested that pyrolysis temperature should be below 500ºC to avoid incomplete biochar formation. In this study, the biochar tested was produced from the pyrolysis of poultry droppings at 400ºC for 48h. Under these conditions, the produced biochar could be used to improve soil fertility by liming effect, enrichment in volatile matter and increase of pore volume (Tomczyk et al., 2020). The results of this research work showed that the analyzed soil chemical parameters (SOC, available phosphorus, exchangeable base cations, CEC, nitrogen and pH) increased in soil with biochar liming.

Although biochar addition rates were relatively low to medium, the increase in soil pH may be due to the high pH values of the added biochar, which can increase the pH of an acidic soil by increasing soil base saturation, decreasing the level of exchangeable aluminum and consuming soil protons. This is consistent with studies that used biochar from crop residues (Smider and Singh, 2014, Yuan and Xu, 2011). Yuan and Xu (2010) indicated

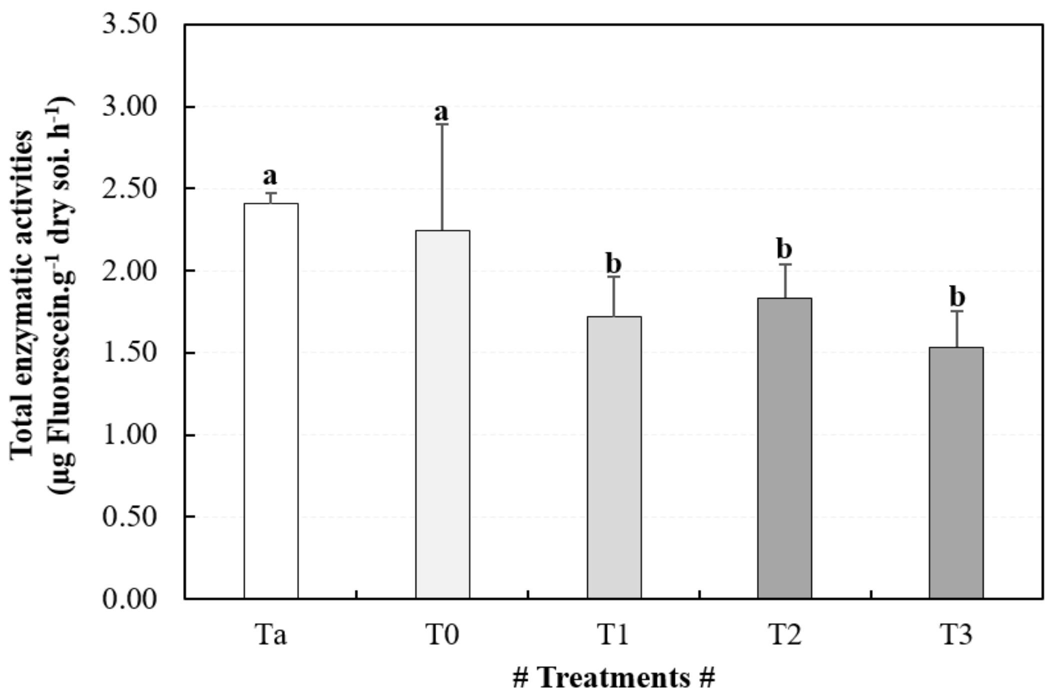

Figure 2. Total enzyme activities of soil amended with biochar (T0 : 0%), (T1 : 8%), (T2 :12%) and (T3 : 16%). Means with the same letter are not significantly different from each other (P>0.05 ANOVA followed by Dunnett comparison test). Error lines represent ± standard deviation of the mean.
Source: Author own data

that soil pH values, after application of biochar, were positively correlated with the buffering power of biochar, due to the presence of abundant organic anions in biochar. However, Wang et al. (2013) demonstrated that besides the buffering power of biochar, the decarboxylation process also played a main role in adjusting acidity. In addition, biochar positively influences pH by providing carbon to heterotrophic microorganisms and accumulating carbonates ($CaCO_3$) following the degassing of CO_2 from microbial activity in the presence of water (H_2O) (Steiner et al., 2007) and by significantly lowering aluminum toxicity through Al complexation and leaching (Zhang et al., 2010). The significant change in pH, in the different treatments with biochar, will have positive effects on phosphorus availability because in tropical soils, phosphorus (P) is fixed at pH below 5 and is available for pH between 6 and 8 (Zhang et al., 2010). The increase in assimilable phosphorus is observed for T2 and T3 treatments compared to the control. The increase in soil pH creates an environment for the release of phosphorus fixed at low pH by Fe and Al ions. Rastija et al. (2010)'s research on acidic soils showed that a gradual increase in pH induces an increase in bioavailable P in soil by reducing exchangeable Al and acid saturation rate.

In the case of exchangeable bases, treatments induced significant increases in the amount of Ca^{2+} and Mg^{2+} cations. The significant release of base cations into the soil is related to the nature of the biochar application. The improvement in base cations could be explained by the rapid mineralization of organic matter from poultry droppings. Katherine et al. (1995) showed that the addition of a basic amendment on an acidic soil during 70 days of testing has been very effective in increasing the amount of Ca^{2+} and Mg^{2+} cations in the soil and especially in correcting soils deficient in Mg^{2+}. This work also showed that the CEC increased in the different treatments in line with earlier reports. Many authors have confirmed the beneficial effect of biochar on the value of soil cation exchange capacity (Schulz and Glaser, 2012). As Cheng et al. (2006) pointed out that, this parameter plays a crucial role in water and nutrient retention for plants. This beneficial effect of biochar on soil cation exchange capacity can be attributed to its physical properties, and in particular to its porous structure and specific surface area (Lei and Zhang, 2013). Lehmann (2007) indicated that biochars produced at a temperature below 400 ºC may have low CEC values and, therefore, a limited effect on soil quality improvement. However, the same author also pointed out that, despite the low CEC, the biochar undergoes an aging process in the soil, resulting in a major increase in Ca^{2+}, Mg^{2+}, K^+ and Na^+ and CEC. This process would be linked to good mineralization in biochar amended soils. In the authors' study, the C/N ratios suggest a good mineralization of organic matter whose contents are significantly improved in soils.

Soil enzyme activity is another important factor used to measure soil fertility and biological activity (Nelissen et al., 2015). In addition, the increase of some of the soil enzymic activities is beneficial to soil carbon and nitrogen cycle. Earlier studies showed that biochar can increase soil enzymic activity (Gul et al., 2015), and the effects vary with biochar and soil types, the dose of biochar and soil enzyme types. In contrat to these earlier studies, this study exhibited that total soil enzymic activity decreased for all soils treated with biochar. Moreover, there was no significant ($P < 0.05$) difference in total soil enzymic activity between the different treatments. According to Teutscherova et al. (2018), the special structure and adsorption properties of biochar determine the complexity of effects of biochar on soil enzymes. The adsorption of biochar to the substrate of reaction is conducive to promote the enzymatic reaction and increase soil enzymic activity; while the adsorption of biochar to enzyme molecule protects the binding site of the enzymatic reaction, which may inhibit the enzymatic reaction. In the authors' case, the change in the total soil enzymic activity between untreated and treated soils could be, in addition, related to increased pH value. Turner (2010) showed each enzyme works best at a specific pH value and changes in pH alter the shape of an enzyme's active site. Thus, an increase in pH results in a sharp decrease in activity. In the case of the microbiological level, the activities of microorganisms translated by enzymatic activity show the effect of biochar amendment on the total microflora in soils. Therefore, this decrease in total soil enzymatic activity could be coupled to a change of bacterial community from strictly acidophilic to basidophilic, as understood from the results of Balland-Bolou-Bi and Poszwa (2012) and Biederman and Harpole (2012) after soil liming.

Effect of biochar application on growth and productivity of Tomato

The plant growth parameters (height, stem diameter and leaves number), over time, experienced in soils amended with or without biochar are presented in Figure 3. The different parameter results are normalized to the same parameter at the first measurement (day 27). Normalization served to account for any unintended differences between the treatments at the time of planting as suggested by Graber et al. (2010). Plant heights were influenced by the doses of biochar over time (Figure 3a). Tomato plant heights were significantly greater in biochar amended soil at all measurement times compared to the control, soil without biochar application. Results showed significant difference between treatment T1 (8%) and other levels of biochar amendment (Figure 3a). Regarding the diameter of the plant stem, the largest diameter comes from the dose of T1 (8%), which is significantly different from T2 (12%) and T3 (16%) and the control T0 (0%) (Figure 3b). For T2 and T3 treatments, no differences were observed over time (Figure 3b). Soil amended with biochar induced significant variability on the number of leaves in the plant (Figure 3c). In contrast to plant height and stem diameter, the number of leave increased significantly with T3 (16%) over time compared to T2 (12%) and T1 (8%) (Figure 3c). For these two treatments, T2 and T1, no differences were observed during plant growing period.

Root and shoot biomasses produced by tomato plants are shown in Figure 4. The shoot biomass of plants from amended soil T1 (54.3±4.33 g), T2 (40.5±3.06 g) and T3 (33.5±4.33 g) were higher than the control treatment T0 (17.1±6.12 g). For root biomass, the T1 treatment yielded the highest biomass with an average value of 16.1±2.1g, which was significantly higher than T0, T2 and T3. For these treatments, the difference in root biomass is not significant (Figure 4). The root/shoot ratio displays value with a higher mean for control close to 50%; while for plants derived from soil amended show a root/shoot ratio, an average close to 30% (Figure 4).

Plant response to biochar doses was assessed by total biomass production at the end of the growth expériment. The data showed a response with a difference between the treatments. The analysis of variance was highly significant between the treatments employed. The lowest biomass was observed with the control treatment T0 (24±4.80g); the biomass reaches its maximum value with the treatment T1 (70.4±3.52 g) before decreasing gradually with the treatments T2 and T3 (Figure 5).

The average number of fruits per treatment ranged from 0 to 12 fruits. Plant from treatment T1 displayed a greater number of fruit per plant with an average of 12±1.69; whereas plants in control treatment T0 did not have fruit (Figure 6).

Plants from treatments T2 and T3 showed a number of fruits between control and T1. Analysis of the variance at the significant 5% threshold with ($p = 0.013$) showed a significant difference between T1 and the other treatements (Figure 6). These results suggested that biochar has an effect on tomato plant growth and productivity, according to specific biochar dose.

The results of this study showed that the biochar liming of soil induced significant effects on the growth and yield parameters of tomato plants (Rawat et al., 2019). Across recent reviews, there is a general consensus that biochar is more likely to result in positive plants' growth responses in acidic soil types (Jeffery et al., 2011; Biederman and Harpole, 2012; Crane-Droesch et al., 2013). The effects of biochar on crops also will be changed by soil properties, the characteristics and dosage of biochar, crop types, climate, the proportion of fertilisers and various comprehensive factors. In this study, similar to soil properties, the growth and yield parameters of tomato were close to applied biochar doses. However, the plant height and biomass of tomato were significantly ($P < 0.05$) increased in the soil under the low biochar level (T2 and T1) which decreased under

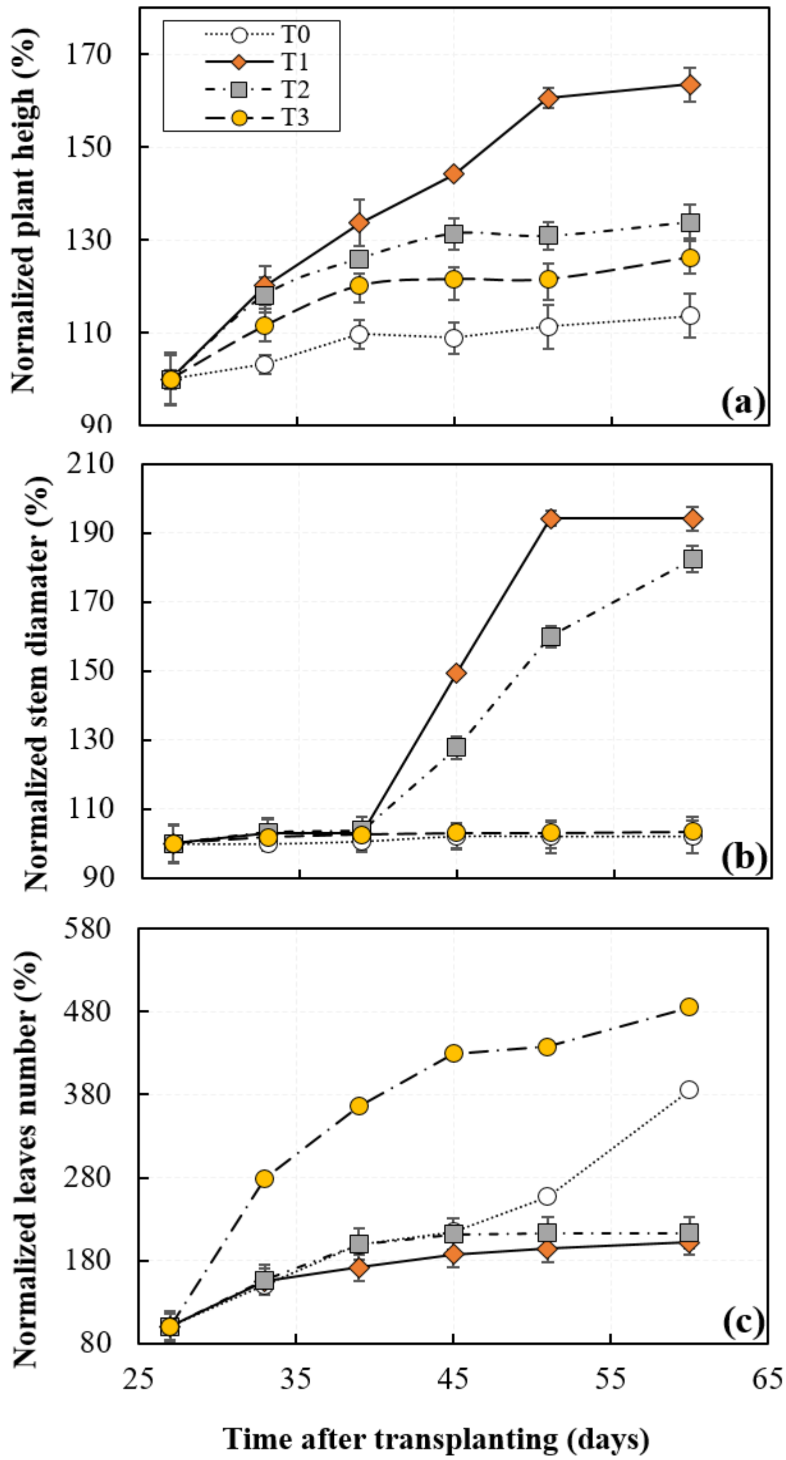

Figure 3. Normalized tomato plant parameters (heigh (a), Stem diameter (b) and leave number (c) measured during plant growth soil amended with biochar (T0 : 0%), (T1 : 8%), (T2 :12%) and (T3 : 16%).
Source: Author own data

the high level (T3). The proportional growth and yield of tomato reflect the benefit of good applied biochar doses. This effect of biochar on plant growth results from direct and indirect actions. Biochar itself contains certain nutrients that can be directly utilised by plants and improve their growth (Fox et al., 2016; Alla et al., 2018).

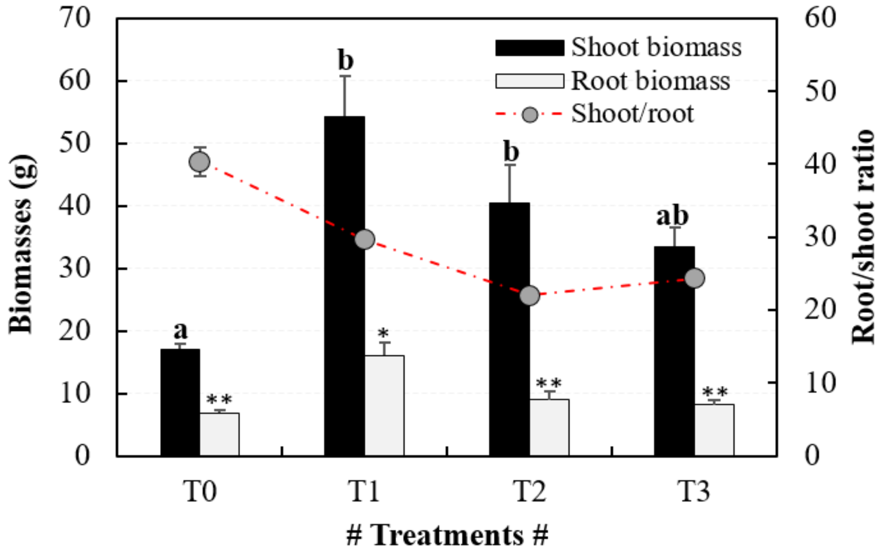

Figure 4. Shoot and root biomasses (histogram) and Root/Shoot ratio (red line) of tomato plant grown on soil amended with biochar (T0 : 0%), (T1 : 8%), (T2 :12%) and (T3 : 16%). Means with the same letter (for shoot) or number of asterisk (for roots) are not significantly different from each other (P>0.05 ANOVA followed by Dunnett comparison test). Error lines represent ± standard deviation of the mean.
Source: Author own data

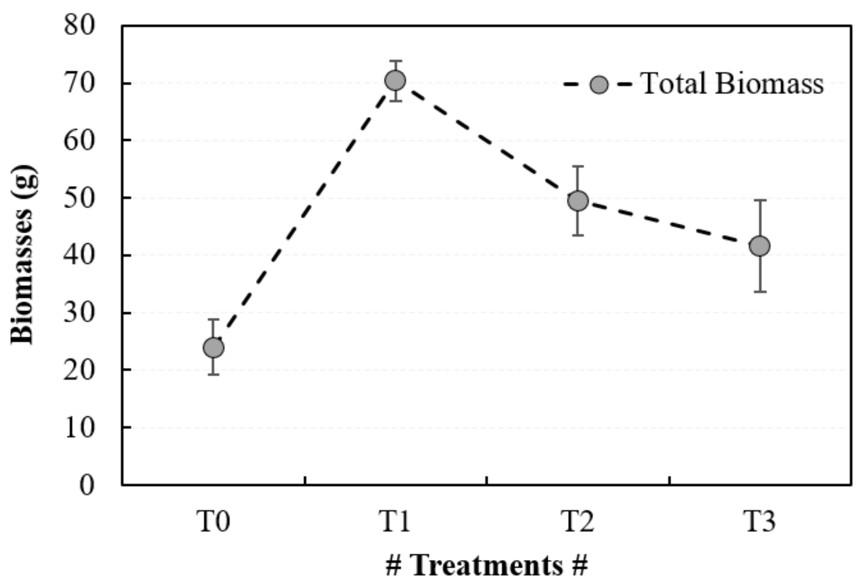

Figure 5. Total tomato plant biomasses produced during the experimental growth on soil amended with biochar (T0 : 0%), (T1 : 8%), (T2 :12%) and (T3 : 16%). Error lines represent ± standard deviation of the mean.
Source: Author own data

Also, biochar indirectly promotes the growth of plants by improving soil chemical properties, enzyme activity, microbiology ecosystems and other environmental conditions (Liu et al., 2014).

For acidic soil, one suitable explanation is that biochar could promote plant growth in acidic soil by the alleviation of Al toxicity through the increase of soil pH. Alleviation of Al toxicity can be attained primarily through liming and also through greater bivalent cations (Mg and Ca) supply, which improves root growth under Al stress (Scott et al.,

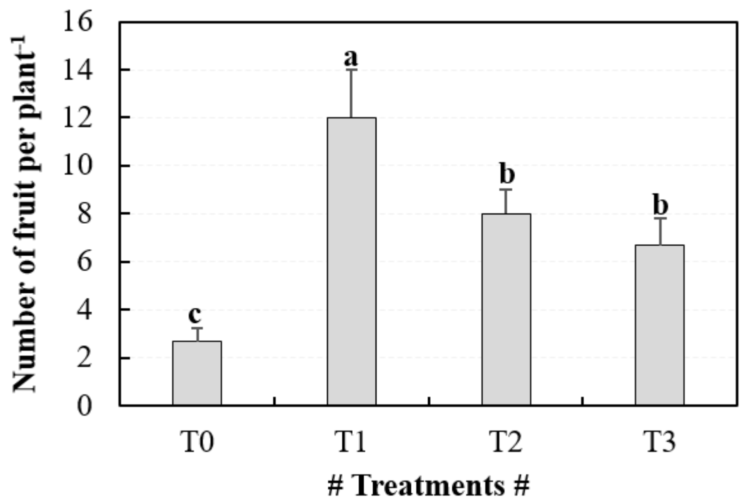

Figure 6. Number of tomato fruit produce per plant during experimental growth on soil amended with biochar (T0 : 0%), (T1 : 8%), (T2 :12%) and (T3 : 16%). Means with the same letter are not significantly different from each other (P>0.05 ANOVA followed by Dunnett comparison test). Error lines represent ± standard deviation of the mean.
Source: Author own data

2008). In this study, the decrease observed with the application of high biochar doses could be explained by excess nitrogen not used by the plant (Biaou, 2010). In addition, some study reported that the effectiveness of some trace elements or the presence of high levels of salt from poultry manure-based biochar could also inhibit plant growth (Revell et al., 2012).

Conclusion

To sum up this study, poultry manure based biochar improved soil pH and chemical properties like CEC, base cation content, available phosphorus, organic carbon and total nitrogen. However, biochar soil liming reduced the enzymic activity of the soil. This suggests there was a decrease in bacterial diversity, relative abundance of bacteria associated with soil carbon and nitrogen cycles, organic matter decomposition, disease control, and promotion of crops’ growth (under the low biochar level) in the acidic soil. Consequently, various doses of biochar used for soil liming did not induce significant difference in the growth of tomato plant; but treatment with 12% of biochar appears to be a better dose for tomato growth in acidic soil. More investigations need to be conducted to better understand the effect of biochar on microbial activities in relation to plant growth in acidic soil.

CONFLICT OF INTERESTS

The authors have not declared any conflicts of interests.

ACKNOWLEDGEMENTS

This experimental work was funded under the World Bank (WB) Program, through the African Centre of Excellence on Climate Change, Biodiversity and Sustainable Agriculture (CEA-CCBAD). The authors would like to thank M. N'Guettia Adou and Kraidy Armel for their lab technical assistance. They also want to thank Prof. Kassi N'dja for his comments and contribution to this manuscript. The authors are grateful to the editor and the reviewers for improving this manuscript.

REFERENCES

Adugna G (2018). A review on impact of compost on soil properties water use and crop productivity. Agricultural Science Research Journal 4(3):93-104.

Alla KT, Bomisso EL, Outtarra G, Dick AE (2018). Effects of fertilisation based on by-products of plantain peel on the agromorphological parameters of the eggplant variety F1 kalenda (Solanum melongena) in the locality of Bingerville in Côte d'Ivoire. Journal of Animal and Plant Sciences 38(3):6292-6306.

Balland-Bolou-Bi C, Poszwa A (2012). Effect of calco-magnesian amendment on the mineral weathering abilities of bacterial communities in acidic and silicate-rich soils. Soil Biology and Biochemistry 50:108-117.

Biaou ODB (2010). Valorization of organic agriculture: effect of different sources of organic fertilizers on the yield and quality of lettuce and carrot on ferralitic soil in southern Benin. Master thesis, Abomey/Calavy University, Benin 81 p.

Biederman LA, Harpole WS (2012). Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis. GCB Bioenergy 5(2):202-214.

Bray RH, Kurtz LT (1945). Determination of Total Organic and Available Forms of Phosphorus in Soils. Soil Science 59:39-45. http://dx.doi.org/10.1097/00010694-194501000-00006

Centre for International Cooperation in Agricultural Research for development (CIRAD) (2017). The production and distribution practices of chicken droppings in Ivory Coast, as part of the project peasant innovation and resilience to climate change in the cocoa plantations of Ivory Coast. Support Program for food and nutrition security in West Africa pp. 4-16.

Cheng CH, Lehmo AJ, Thies JE, Burton SD, Engelhard MH (2006). Oxydation of black carbon by biotic and abiotic process. Organic Geochemistry 37(11):1477-1488

Ciesielski H, Sterckeman T, Santerne M, Willery JP (1997). A Comparison between Three Methods for the Determination of Cation Exchange Capacity and Exchangeable Cations in Soils. Agronomie 17(1):9-16. https://doi.org/10.1051/agro:19970102

Crane-Droesch A, Abiven S, Jeffery S, Torn M (2013). Heterogeneous global crop yield response to biochar: A meta-regression analysis. Environmental Research Letters 8(4):044049. Availaible at: https://iopscience.iop.org/article/10.1088/1748-9326/8/4/044049/pdf.

Darrell WN, Lee ES (1980). Total Nitrogen Analysis of Soil and Plant Tissues. Journal of Association of Official Analytical Chemists 63(4):770-778. https://doi.org/10.1093/jaoac/63.4.770

Downie A, Crosky A, Munroe P (2009). Physical properties of biochar. In: Lehmann J, Joseph S. (Eds.), Biochar for Environmental Management: Science and Technology (pp. 227-249). London: Earthscan Publications Ltd.

Food and Agriculture Organization of the United Nations (FAO) (2004). Drought-resistant Soils: Optimization of Soil Moisture for Sustainable Plant Production. FAO Information Division, Rome. Available at: https://www.fao.org/3/a0072e/a0072e00.htm

Fox A, Gahan J, Ikoyi I, Kwapinski W, O'Sullivan O, Cotter PD, Schmalenberger A (2016). Miscanthus biochar promotes growth of spring barley and shifts bacterial community structures including phosphorus and sulfur mobilizing bacteria. Pedobiologia 59(4):195-202.

Gillian A, Duncan H (2001). Development of a sensitive and rapid method for the measurement of total microbial activity using fluorescein diacetate (FDA) in a range of soils. Soil Biology and Biochemistry 33(7-8):943-951. https://doi.org/10.1016/S0038-0717(00)00244-3

Glaser B, Lehmann J, Zech W (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal - a review. Biology and Fertility of Soils 35:219-230.

Gnimassoun KEG, Ettien DJB, Bouadou OBF, Masse D (2020). Effect of Empty Fruit Bunch Compost on Improving the Productivity of Two Vegetables Produced under Sandy Poor Soil in Organic Matter in the South-West of Côte d'Ivoire. European Journal of Scientific Research 157(2):142-157.

Graber ER, Meller Harel Y, Kolton M, Cytryn E, Silber A, David DR, Tsechansky L, Borenshtein M, Elad Y (2010). Biochar impact on development and productivity of pepper and tomato grown in fertigated soilless media. Plant Soil 337:481-496.

Gul S, Whalen JK, Thomas BW, Sachdeva V, Deng HY (2015). Physico-chemical properties and microbial responses in biochar-amended soils: mechanisms and future directions. Agriculture Ecosystems and Environment 206:46-59.

Jeffery S, Verheijen FGA, van der Velde M, Bastos AC (2011). A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis, Agriculture, Ecosystems and Environment 144:175-187.

Jha P, Biswas AK, Lakaria BL, Rao AS (2010). Biochar in agriculture - prospects and related implications. Current science 99:1218-1225.

Katherine SR, David LR, Keith SJ (1995). Effect of liming on the chemical composition of soils. Journal of the Science of Food and Agriculture 199(89):159-167.

Laghari M, Naidu R, Xiao B, Hu R, Mirjat MS, Hu M, Kandhro MN, Chen Z, Guo D, Jogi Q, Abudi ZN, Fazal S (2016). Recent developments in biochar as an effective tool for agricultural soil management: a review. Journal of Science and Food Agriculture 96(15):4840-4849.

Lal R (2015). Sequestering carbon and increasing productivity by conservation agriculture. Journal of Soil and Water Conservation 70:55A-62A.

Lanna NBL, Silva PNL, Colombari LF, Corrêa C V, Cardoso AII (2013). Residual effect of organic fertilization on radish production. Horticultura Brasileira 36(1):47-53.

Lehmann J (2007). Bio-energy in the black. Frontiers in ecology and the environment 5:381-387.

Lehmann J, Gaunt J, Rondon M (2006). Biochar sequestration in terrestrial ecosystems - a review. Mitigation and Adaptation Strategies for Global Change 11:403-427.

Lehmann J, Rillig MC, Thies J, Masiello CA, Hockaday WC, Crowley D (2011). Biochar effects on soil biota - A review. Soil Biology and Biochemistry 43:1812-1836.

Lei O, Zhang R (2013). Effects of biochars derived from different feedstocks and pyrolysis temperatures on soil physical and hydraulic properties. Journal of Soils and Sediments 13:1561-1572.

Liu E, Changrong Y, Xurong M, Wenqing H, So HB, Linping D, Qin L, Shuang L, Tinglu F (2010). Long-term effect of chemical fertilizer, straw, and manure on soil chemical and biological properties in north west China. Geoderma 150:173-180.

Liu Z, Chen X, Jing Y, Li Q, Zhang J, Huang Q (2014). Effects of biochar amendment on rapeseed and sweet potato yields and water stable aggregate in upland red soil. Catena 123:45-51.

Nelissen V, Ruysschaert G, Manka AD, D'Hose T, De Beuf K, Al-Barri B, Cornelis W, Boeckx P (2015). Impact of a woody biochar on properties of a sandy loam soil and spring barley during a two-year field experiment. European Journal of Agronomy 62:65-78.

Noor MN, Shariff A, Abdullah N, Syairah A (2019). Temperature effect on biochar properties from slow pyrolysis of coconut flesh waste. Malaysian Journal of Fundamental and Applied Sciences 15:153-158.

Rastija M, Kovacevic V, Rastija D, Ragályi P, Andric L (2010). Liming impact on soil chemical properties. In Maric S, Loncaric Z. (Eds), Proceedings of the 45th Croatian & 5th International Symposium on Agriculture. Osijek, Croatia pp. 124-127.

Rawat J, Saxena J, Sanwal P (2019). Biochar: A Sustainable Approach for Improving Plant Growth and Soil Properties. Available at: https://doi.org/10.5772/intechopen.82151.

Revell K, Maguire R, Agblevor F (2012). Field trials with poultry litter biochar and its effect on forages, green peppers, and soil properties. Soil Science 177(10):573-579.

Sangaré A, Koffi E, Akamou F, Fall CA (2009). National report on the state of plant genetic resources for food and agriculture. Ivory Coast 18 p.

Schulz H, Glaser B (2012). Effects of biochar compared to organic and inorgnic fertilizers on soil quality and plant growth in a greenhouse experiment. Journal of plant Nutrition and Soil Science 175(3):410-422.

Scott BJ, Ewing, MA, Williams R, Humpheries AW, Coombes NE (2008). Tolerance of aluminium toxicity in annual Medicago species and lucerne. Australian Journal of Experimental Agriculture 48:499-511.

Smider B, Singh B (2014). Agronomic performance of a high ash biochar in two contrasting soils. Agriculture, Ecosystems and Environment 191:99-107.

Srivastava AK (2009). Integrated nutrient management: concept and application in citrus: citrus II. Tree Forestery Sciences and Biotechnology 3:32-58.

Steiner C, Teixeira W, Lehmann J, Nehls T, Macêdo J, Blum W, Zech W (2007). Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. Plant and Soil 291:275-290. https://doi.org/10.1007/s11104-007-9193-9.

Steinbeiss S, Gleixner G, Antonietti M (2009). Effect of biochar amendment on soil carbon balance and soil microbial activity. Soil Biology and Biochemistry 41:1301-1310.

Teutscherova N, Lojka B, Houška J, Masaguer A, Benito M, Vazquez E (2018). Application of holm oak biochar alters dynamics of enzymatic and microbial activity in two contrasting Mediterranean soils. European Journal of Soil Biology 88:15-26.

Thies JE, Rillig M (2009). Characteristics of biochar: biological properties. In: Lehmann J, Joseph S. (Eds.), Biochar for Environmental Management: Science and Technology (pp. 85-105). London: Earthscan Publications Ltd.

Tomczyk A, Sokołowska Z, Boguta P (2020). Biochar physicochemical properties: pyrolysis temperature and feedstock kind effects. Review in Environmental Science and Biotechnology 19:191-215.

Turner BL (2010). Variation in pH optima of hydrolytic enzyme activities in tropical rain forest soils. Applied and Environmental Microbiology 76(19):6485-6493.

Verheijen F, Jeffery S, Bastos A, Velde M, Diafas I (2010). Biochar Application to Soils - A Critical Scientific Review of Effects on Soil Properties, Processes and Functions. JRC Scientific and Technical Reports, JRC55799. Available at: https://op.europa.eu/en/publication-detail/-/publication/f0a7ae57-49b5-4986-8751-74cb068d4a83/language-en.

Vitti C, Stellacci A, Leogrande R, Mastrangelo M, Cazzato E, Ventrella D. (2016). Assessment of organic carbon in soils: A comparison between the Springer-Klee wet digestion and the dry combustion methods in Mediterranean soils (Southern Italy). CATENA 137:113-119. 10.1016/j.catena.2015.09.001

Wang J, Pan X, Liu Y, Zhang X, Xiong ZZ (2013). Effects of biochar amendment in two soils on greenhouse gas emissions and crop production. Plant Soil 360:297-298.

Yuan J, Xu RK (2010). The amelioration effects of low temperature biochar generated from nine crop residues on an acidic Ultisol. Soil Use and Management 27(1):110-115.

Yuan J, Xu RK, Zhang H (2011). The forms of alkalis in the biochar produced from crop residues at different temperatures. Bioresource technology 102(3):3488-3497.

Zanutel M (2019). Long-term impact of biochar on the physical and hydrodynamic properties of soil as well as on water flows and stocks in temperate environments. Master thesis, Leven University. Available at: https://dial.uclouvain.be/memoire/ucl/fr/object/thesis%3A19439

Zhang A, Cui L, Pa G, Li L, Hussain Q, Zhang X, Zheng J, Crowley D. (2010). Effect of biochar amendment on yield and methane and nitrous oxide emissions from a rice paddy from Tai Lake plain, China. Agriculture, Ecosystems and Environment 139(4):469-475.

Zhao B, O'Connor D, Zhang J, Peng T, Shen Z, Tsang D, Hou D (2018). Effect of pyrolysis temperature, heating rate, and residence time on rapeseed stem derived biochar. Journal of Cleaner Production 174:977-987.