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Determination of optimal doses and periods of biochar and compost application on maize productivity in the sudanian zone of Chad

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ABSTRACT

The sandy-loam soils of the Sudanian zone of Chad were subject to increased depletion. One of the solutions to this problem of declining soil fertility would be to apply a reasoned organic fertilisation. The aim of this study was to evaluate the fertilising potential of biochar and compost on this depleted soil and to determine the optimal doses and the best periods of application on maize. Seven treatments with inputs such as two weeks before sowing, during sowing and two weeks after emergence were conducted in controlled environment : the control, soil + 5tha^{-1} of biochar, soil + 7.5tha^{-1} of biochar, soil + 10tha^{-1} of biochar, soil + 5tha^{-1} of biochar + 5tha^{-1} of compost, soil + 7.5tha^{-1} of biochar + 5tha^{-1} of compost, soil + 10tha^{-1} of biochar + 5tha^{-1} of compost. Each treatment was repeated four times. Eight agro-morphological variables were evaluated: vigour of plant, harvested plant ratio, cob circumference, cob length, cob weight, plant height on maturity, weight of one thousand grain and aerian biomass yield. These variables showed that growth and yield are clearly improved on fertilized treatements whatever dose and bringing period (in average: $3 \leq VIG \leq 7$, $41.7 \leq TPR \leq 91.7\%$, $7.9 \leq CIE \leq 11.4$ cm, $66.4 \leq POE \leq 83.4$g, $115.2 \leq PMG \leq 187.3$g) comparatively to control (VIG = 3, TPR = 25%, CIE = 6.5 cm, POE = 51.9g, PMG = 102g). These results confirmed more the importance of biochar and compost on soils fertilisation. The treatment at two weeks before seedling for 10tha^{-1} of biochar alone and 10tha^{-1} of biochar+5tha^{-1} of compost were judged the best indicated to be applied in the field like alternative to chemical fertiliser for the best maize productivity in the sudanian zone of Chad.

Keywords: Chad, biochar, compost, productivity, maize, dose.

Détermination des doses optimales et des périodes d'apport de biochar et de compost sur la productivité du maïs dans la zone soudanienne du Tchad

RESUME

Les sols sablo-limoneux de la zone soudanienne du Tchad sont sujets aux phénomènes d'appauvrissement accru. L'une des solutions pour palier à ce problème de baisse de fertilité des sols serait d'apporter une fertilisation organique raisonnée. Cette étude avait pour but d'évaluer le potentiel fertilisant du

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biochar et du compost sur ce sol appauvri et déterminer les doses optimales et les meilleures périodes d'apport sur du maïs. Sept traitements aux apports à deux semaines avant le semis au semis et deux semaines après la levée ont été conduits en milieu contrôlé : sol témoin, sol + 5t/ha de biochar, sol + 7,5t/ha de biochar, sol + 10t/ha de biochar, sol + 5t/ha de biochar + 5t/ha de compost, sol + 7,5t/ha de biochar + 5t/ha de compost, sol+10t/ha de biochar + 5t/ha de compost. Chaque traitement a été répété quatre fois. Huit variables agromorphologiques ont été évaluées : vigueur de la plante à la levée, taux des plantes récoltées, circonférence de l'épi, longueur de l'épi, le poids de l'épi, hauteur de la plante à maturité, poids de mille grains, rendement de biomasse aérienne. Ces variables ont montré que les croissances et les rendements sont nettement améliorés dans les traitements fertilisés au biochar et compost quelques soit la dose et la période d'apport (en moyenne : $3 \leq VIG \leq 7$, $41,7 \leq TPR \leq 91,7\%$, $7,9 \leq CIE \leq 11,4$ cm, $66,4 \leq POE \leq 83,4$g, $115,2 \leq PMG \leq 187,3$g) comparativement au témoin (VIG = 3, TPR = 25%, CIE = 6,5 cm, POE = 51,9g, PMG = 102g). Ces résultats confirment davantage l'importance capitale du biochar et du compost dans la fertilisation des sols. Les traitements à deux semaines avant le semis pour les doses de 10t/ha de biochar seul et de 10 t/ha de biochar+5t/ha de compost ont été jugées les mieux indiquées à être appliquées en champ en alternatif aux engrais chimiques pour une meilleure productivité de maïs en zone soudanienne du Tchad.

Mots clés : Tchad, biochar, compost, productivité, maïs, dose.

INTRODUCTION

In the dry tropical zone of sub-Saharan Africa, particularly in Chad, cultivation with inappropriate practices and increasingly intensive farming due to the growing needs of the increasing population and the lack of arable land degrade the land (Kasongo et al., 2013; Bahouro et al., 2022). This results in a rapid decrease in soil organic carbon (SOC) content and the appearance of deficiencies in various mineral elements. Crop yields decrease and the land is sometimes abandoned (Fábio et al., 2020). The use of chemical fertilisers can increase yields, but they pollute the environment and are inaccessible to farmers because of their cost and unavailability (Sanchez, 2002; Naitormbaide et al., 2010; Useni et al., 2013; Tahir et al., 2021). Soil fertility improvement techniques, including improved fallow practices, the use of management techniques such as crop rotation, the use of soluble fertilisers and crop association are good methods for restoring and improving soil productivity. However, these techniques no longer appear to be effective in the long term in the current context of climate change, population growth and other factors contributing to food insecurity (Gove, 2015). Hence the need to establish an indispensable, efficient and environmentally friendly sustainable and productive agricultural system aimed at restoring soil fertility through organic amendments in order to ensure food security for populations. Authors (Khalid et al. 2014; Sikuzani et al., 2014; Siene et al., 2020; Tchabi et al., 2012; Weber et al., 2007; Biaou et al., 2017) have shown that organic amendments can maintain or improve soil fertility in a more sustainable way. Therefore, objective of this work was to test the effectiveness of biochar and compost in a controlled environment and to determine the best doses and the best period(s) of their application on maize productivity in the Sudanian zone of Chad.

MATERIALS AND METHODS

Presentation of the study area

The study area is located in the sudanian zone of Chad between 8 and 9 degrees North latitude and 14 and 15 degrees East longitude (Figure 1). The climate is Sudano-Guinean with an average annual rainfall of 1000 mm (Aubreville, 1950; Pias, 1970; DREM, 2022). The hydrographic network of the area is made up of a few fairly large rivers, most commonly called Mayo or El, which flow through the hills and form swampy areas at low points (Salzabo, 2013). The vegetation is the Sudano-Guinean domain, the main ones being the forest tree savannah, the very clear tree savannah, the vegetation consisting of relics of cultivated areas and the massif vegetation (Gondrard, 1964; CNAR, 2015). Soil types include sesquioxide soils, hydromorphic soils, crude mineral soils, poorly developed soils and the juxtaposition of several soil types or classes (Pias, 1964; Cheverry and Fromaget, 1970). The geology of the area consists mainly of basement outcrops, Terminal continental, Cretaceous and Quaternary formations (Gerard, 1958).

The population of the study area is cosmopolitan and engages in agricultural, pastoral, mining and even commercial activities. The main food crops are sorghum, maize, rice, millet, sesame, cassava, cowpeas and groundnuts. Cash crops remain based solely on cotton (FAO, 2012; Djetoguem, 2015).

The soil used

The soil used was taken from the site to be used for the field trial. The 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 mixture in order to obtain a homogeneous sample. The sample was quartered. The two diagonals are then mixed for use in pots.

The pots used in this project are transparent plastics with a height of 40 cm and a diameter of 20 cm and a volume of 12560 cm^3.

Plant material

The plant material used was the 2009 TZEE-W maize variety with a sowing-maturity cycle (50%) of 80 days called "90 days" by the farmers of the zone. The variety has an extra-early cycle, white seed colour and a potential yield of 4 to 5.5 t/ha.

Fertilising material

The biochar used is derived from millet stalks. It was ground in a porcelain mortar and sieved through a stainless steel sieve to obtain particle sizes of 2mm or less for laboratory analysis. For the trial use, it was ground to a powder also by crushing.

The compost used in this experiment was made from original material consisting of cow dung, grass and kitchen ash. The fraction with dimensions less than or equal to 2mm obtained by sieving was intended for laboratory analysis. The final product (compost) was used directly for the test.

Soil and fertilising material analysis

Two types of analysis were carried out on the soil, biochar and compost: physicochemical and geochemical analysis.

The physico-chemical analyses were carried out on samples smaller than 2 mm at the ‘Laboratoire d'Analyses de Sols-Eaux-Plantes’ of the ‘Institut Tchadien de Recherche Agronomique pour le Développement’ (ITRAD). Geochemical analysis (major and trace metals) were carried out at the Geology Laboratory of the University of Johannesburg in South Africa.

For the physico-chemical analyses, pH and conductivity were determined by the soil solution method at a soil/water ratio of 1/2.5 and 1/50 respectively. Granulometry was carried out only on the soil sample by the densimetric method. Organic matter was determined by the Walkley and Black method modified by Grahm. Total nitrogen was determined by mineralisation of the sample by the Khjedahl method. Assimilable phosphorus was measured by the Bray 1 method.

Geochemical analyses of major elements were determined by X-ray fluorescence spectrometry. This consists of subjecting samples to analysis at Wave lenght energy Dispersive Spectrometry (WEDS), which performs qualitative and quantitative measurements. The analysis of trace elements in samples was carried out by Inductively Coupled Plasma Mass Spectrometry (ICP-MS).

Conducting pot trials

The trials were conducted in pots in a controlled environment on the site of the Laboratory of the Chadian Institute of

Agronomic Research for Development. Soil samples were taken at depths of 0-25 cm in the study area.

In each pot, six (06) kg of soil were introduced. The fertiliser inputs were:

- Biochar alone and/or compost two (2) weeks before sowing (2SAS), during sowing (PS), two (2) weeks after emergence (2SAL).
- Sowing with 3 maize seeds per pot.
- Dematting at two (02) plants per pot on the 15th day after sowing.
- Maintenance and follow-up work from emergence to maturity.

Experimental set-up and treatments

The experimental set-up is a block consisting of seven (7) treatments for three types of periodic inputs (2SAS, PS and 2SAL) repeated four times. That is 88 experimental units. The treatments are:

- No input

MC0: control without fertiliser.

- With biochar only

MC-B1: treatment with 5t/ha of biochar;

MC-B2: treatment with 7.5t/ha of biochar;

MC-B3: treatment with 10t/ha of biochar.

- With biochar and compost

MC-BC1: treatment with 5t/ha biochar + 5t/ha compost;

MC-BC2: treatment with 7.5t/ha biochar + 5t/ha compost;

MC-BC3: treatment with 10t/ha biochar + 5t/ha compost.

Measured agromorphological variables

The agromorphological variables measured were plant vigour at emergence (VIG), rate of plants harvested (TPR) per treatment, average plant height at maturity (HPM), average thousand seed weight (TKW), average above-ground biomass yield (ABB), average ear length (LOE), ear weight (POE) and average ear girth (CIE).

Statistical analysis of the variables

Statistical analysis of the data was performed using SPSS version 25 and Excel 2013. The Pearson test was used to correlate the different variables. The Excel software was used to produce the variation curves.

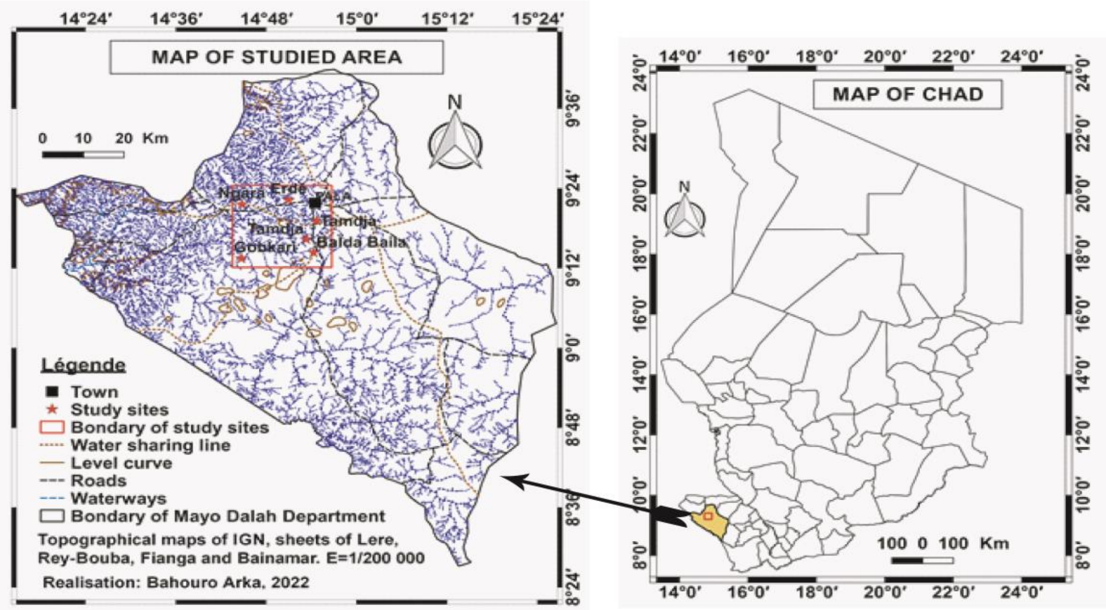

Figure 1: Map of the location of the soil sampling site.

RESULTS

Physico-chemical characteristics of soil, biochar and compost

The soil analysed, whose physico-chemical characteristics are indicated in Table 1, is of the sandy-loam type with a weak acidic pH (6.90), a low electrical conductivity (149µS/cm), a very low level of organic matter (0.6%), a very low level of total nitrogen (0.03%) and a very low level of assimilable phosphorus (0.5 ppm).

Biochar and compost had alkaline and slightly alkaline pH values (9.22 and 7.49), extremely high and very high electrical conductivities (6210 and 788 µS/cm), very high organic matter levels (57.8 and 21.7%), very low and very high total nitrogen levels (0.04 and 0.4%), and high assimilable phosphorus levels (68.3 and 156.3 ppm) respectively.

Geochemical characteristics of soil, biochar and compost

The soil analysed has a very high silica content (96.92%) and very low contents of Al_2O_3, Fe_2O_3, K_2O and TiO_2 (respectively 1.20%, 0.79%, 0.18% and 0.35%). The chemical and mineralogical alteration indices (CIA and MIA) showed that the soil was highly altered, with significant removal of bases (Ca^{2+}, Na^+ and K^+) (Table 2). The contents of metallic trace elements were Cr (32.5ppm), Mn (176ppm), Co (0-4.7ppm), Ni (10.7ppm), Cu (7.8ppm), Zn (4.5ppm), Se (0.3ppm), Cd (0.0ppm), Pb (4.3ppm); it can be seen that the contents of Cr, Mn and Nickel are high (Table 3) .

The biochar showed contents of Cr (18.3ppm), Mn (70.9ppm), Co (0.4ppm), Ni (2.0ppm), Cu (14.3ppm), Zn (45.5ppm), Se (0.2ppm), Cd (0.0ppm), Pb (0.9 ppm) (Table 3) while compost showed contents of Cr (40.8ppm), Mn (345.7ppm), Co (4.8), Ni (9.2ppm), Cu (14.9ppm), Zn (53.4ppm), Se (0.7ppm), Cd (0.1), Pb (7.0) (Table 3).

Observed and measured agomorphological variables

Table 4 below shows the agromorphological variables from the controlled trial.

Statistical analysis

Table 5 and the plot of the components in space after rotation show the correlation matrix between the different agromorphological variables studied. It allows us to observe the different correlations that exist between them. It can be seen that the vigour of the plant at emergence was positively correlated with the rate of harvested plants (r = 0.552) per treatment and per application period, with the height of the plant at maturity (r = 0.471), with the length of the ear (r = 0.481) and very significantly with the weight of the ear (r=0.673). Ear length was also positively correlated with the rate of harvested plants (r = 0.496), significantly correlated with ear weight (r = 0.503) and very significantly positively correlated with plant height at maturity (r = 0.609). Above-ground biomass yield was strongly positively correlated (r = 0.597) with plant height at maturity.

Effect of different treatments and biochar application periods on agromorphological variables

Figure 2 shows the variation curves of the agronomic variables according to the doses and application periods. The curves show peaks in the 5t/ha and 10t/ha treatments at the 2SAS inputs; while the 7.5t/ha treatment shows a greater result at the seed input (PS).

Effect of biochar on plant vigour at emergence (VIG)

Table 1 presents the results of the effect of the different treatments and the periods of biochar application on plant vigour (VIG). The different treatments showed the same behaviour depending on the biochar application. However, the applications two weeks before sowing showed the best results in all treatments (VIG = 7). The inputs at sowing (PS) were less important (VIG = 5) than the inputs before sowing and more important than the inputs at emergence (VIG=3). The control showed similar results to the pre-emergence inputs.

Effect of biochar on the percentage of plants harvested (TPR)

The percentage of plants harvested (TPR) indicates the plants that have completed their full vegetative cycle from emergence to maturity and have produced at least one spike. The TPR was found to be treatment dependent (Table 1). The 10 t/ha biochar treatment gave the best results with an overall high rate observed at the 2SAS input (TPR=100%) followed by the PS and 2SAL inputs (TPR=75% each). The 7.5 tonnes per hectare treatment gave a result of 75% of plants harvested in the PS period while the 2SAS and 2SAL inputs gave rates of 50% each. The 5 tonnes per hectare treatment resulted in 75% of the plants producing in the 2SAS and PS periods, while the 2SAL treatment was 50%. The control showed a rate of 25% of the plants harvested.

Effect of biochar on plant height at maturity (HPM)

In Table 1, it can be seen that overall the best heights are observed in the 10 t/ha treatment and more precisely in the 2SAS inputs (145 cm against 134 cm in PS and 135.5 cm in 2SAL). For the 7.5 t/ha treatment, the input during sowing has the highest height (131.7 cm for 2SAS, 133.7 cm for PS and 131.7 cm for 2SAL). For the 5t/ha treatment, the plant height variable decreases according to the application period (137.3 cm for 2SAS, 132 cm for PS and 128.7 cm for 2SAL). It can be observed that the more the height decreases, the more the application period is delayed. The control has a high height (138.3 cm).

Effect of biochar on ear length (LOE)

The average ear lengths are presented in Figure 7. The 10 t/ha treatment gave average lengths of 11 cm, 7 cm and 7 cm for the 2SAS, PS and 2SAL application periods respectively. At 7.5 t/ha the average lengths are 9.1 cm, 11 cm and 9 cm for 2SAS, PS and 2SAL respectively. For the 5t/ha treatment lengths of 9.5 cm, 8.7 cm and 9.1 cm are observed for 2SAS, PS and 2SAL respectively. The control gives an average length of 9 cm.

Effect of biochar on ear circumference (CIE)

The different treatments had an effect on the ear diameter as shown in Figure 8. The 10 t/ha treatment gave results such as 12 cm, 11.4 cm and 10.8 cm for the 2SAS, PS and 2SAL application periods respectively. The 7.5 t/ha treatment gave a value of 10.1 cm, 10.6 cm and 10 cm for the 2SAS, PS and 2SAL periods respectively. The 5 t/ha treatment gave an average circumference of 10 cm, 10.8 cm and 9.6 cm for the 2SAS, PS and 2SAL periods respectively. The control gave a girth of 6.5 cm.

Effect of biochar on ear weight (POE)

The average values of ear weights are presented in Table 1. The 10 t/ha treatment gave results such as 68.9g, 76.6g and 95.1g for the 2SAL, PS and 2SAS application periods respectively. The 7.5 t/ha treatment gave values of 74.9g, 74.8g and 82.6g for the 2SAL, PS and 2SAS periods, respectively. The 5 t/ha treatment has a POE of 64.7g, 66.6g and 83.3g for the 2SAL, PS and 2SAS periods respectively. The control shows a weight of 51.9g.

Effect of biochar on thousand grain weight (PMG)

Biochar had an effect on thousand kernel weight as shown in Table 1. It can be seen that compared to the control (OCM), the 10 t/ha treatment has weights of 142.3g, 141.4g and 113.5g for the 2SAS, PS and 2SAL periods respectively. The 7.5 t/ha treatment gives weights of 105.3 137.1 and 103.1 for the 2SAS, PS and 2Sal periods respectively. The 5 t/ha treatment gave weights of 136.3, 128.2 and 110.4 g for the 2SAS, PS and 2SAL periods respectively.

Effect of biochar on average aboveground biomass yield (RBA)

The different biochar treatments alone had an effect on the average aboveground biomass yield (Table 1). The 5 t/ha treatment gave average above-ground biomass yields in terms of weight of 111.4 g, 91.5 g and 92.5 g for the 2SAS, PS and 2SAL application periods respectively. With the 7.5 t/ha treatment, the weights for the 2SAS, PS and 2SAL periods are 96.8 g, 106.2 g and 121.3 g respectively. The 10 t/ha treatment gives weights of 101.2 91.3 and 105.1 g for 2SAS, PS and 2SAL respectively.

Effect of different treatments and periods of biochar and compost application on agromorphological variables

Figure 3 shows the variation of the agronomic variables according to the doses and periods of application. The curves show peaks in the 7.5 t/ha and 10 t/ha treatments at the 2SAS inputs; while the 5 t/ha treatment shows a result where some parameters evolve in the opposite direction to the others.

Effect of biochar and compost on plant vigour at emergence (VIG)

Figure 12 shows the effect of the different treatments and the timing of biochar and compost on plant vigour (VIG). The different treatments showed the same behaviour depending on the combined input of biochar and compost. However, the 2SAS inputs showed the best results in all treatments (VIG = 7). The PS inputs were less (VIG = 5) than the pre-seeding inputs and more important than the post-emergence inputs (VIG = 3).

Effect of biochar and compost on the percentage of plants harvested (TPR)

The percentage of plants harvested (TPR) indicates plants that have completed their full vegetative cycle from emergence to maturity and have produced at least one spike. It was found that the TPR is treatment dependent. The 5t/ha treatment gave better results with observed rates of 75, 25 and 25% for the 2SAS, PS and 2SAL periods respectively. The 7.5 t/ha treatment gave rates of 75, 75 and 25% for the 2SAS, PS and 2SAL periods respectively. The 10 t/ha treatment gave results of 100, 100 and 75% for the 2SAS, PS and 2SAL periods respectively. The control had 25% of the plants harvested (Figure 13).

Effect of biochar and compost on average plant height at maturity (HPM)

The average height of the plants at maturity is shown in Figure 14. Heights of 136.7 cm, 125.3 cm and 95 cm were found for the 2SAS, PS and 2SAL periods respectively at the 5 t/ha treatment. The 7.5 t/ha treatment gave heights of 141.7 cm, 141.7 cm and 128.3 cm respectively for the perioids for the 2SAS, PS and 2SAL periods. The 10t/ha treatment had heights of 137.3 cm, 116.7 cm and 117.7 cm for the 2SAS, PS and 2SAL periods respectively.

Effect of biochar and compost on average ear length (LOE)

The average ear lengths are presented in Figure 3. 6 cm and 5 cm lengths are observed for the 2SAS, PS and 2SAL treatments respectively for the 5 t/ha treatment. At 7.5 t/ha, the average lengths are 8.5 cm, 8.8 cm and 5 cm for 2SAS, PS and 2SAL respectively. At 10 t/ha the average lengths are 11.2 cm, 7.7 cm and 5.3 cm for the 2SAS, PS and 2SAL application periods respectively.

Effect of biochar and compost on ear circumference (CIE)

The different treatments had an effect on the ear diameter as shown in figure 16. The 5 t/ha treatment gave an average ear circumference of 7.4 cm, 10 cm, and 8.7 cm for the 2SAS, PS and 2SAL periods respectively. The 7.5 t/ha treatment gave a value of 9.3cm, 8.5cm and 6cm for the period 2SAS, PS and 2SAL respectively. The 10 t/ha treatment gave results such as 8.9 cm, 7.7 cm and 8.9 cm for the 2SAS, PS and 2SAL application periods respectively.

Effect of biochar and compost on ear weight (POE)

Table 1 shows the average ear weight values of the biochar+compost combination. The 10 t/ha treatment gave results such as 75.1g, 78.8g and 96.3g for the 2SAL, PS and

2SAS application periods respectively. The 7.5 t/ha treatment gave values of 64.1g, 66.5g and 70.9g for the 2SAL, PS and 2SAS periods, respectively. The 5 t/ha treatment had a POE of 62.4g, 62.3g and 74.6g for the 2SAL, PS and 2SAS periods respectively. The control showed a weight of 51.9g.

Effect of biochar and compost on thousand seed weight (PMG)

Figure 3 shows the hundred grain weight of each treatment according to the application periods. It can be seen that compared to the control (MC0), the 5 t/ha treatment gave weights of 92.6g, 167.2g and 161.3g for the 2SAS, PS and 2Sal periods respectively. The 7.5 t/ha treatment gave weights of 178.1 g, 165.6 g and 168.5g for the 2SAS, PS and 2Sal periods respectively. The 10 t/ha treatment showed weights of 190.9 g, 179.9 g and 191.0 g for 2SAS, PS and 2SAL respectively.

Effect of biochar and compost on average aboveground biomass yield (RBA)

Figure 3 shows the average above-ground biomass yield at the different biochar treatments alone. The 5 t/ha treatment gave average above-ground biomass yields in terms of weight of 109.4g 112.7g and 58.6g for the 2SAS, PS and 2SAL input periods respectively.With the 7.5 t/ha treatment, the weights for the 2SAS, PS and 2SAL periods were 108.7g, 89.5g and 133.7g respectively.The 10 t/ha treatment gave weights of 126.0g, 69.3g and 84.3g for 2SAS, PS and 2SAL respectively.

Table 1: Physico-chemical parameters of soil, biochar and compost samples.

Samples	**Particle size**			**pH_{eau}**	**pH_{KCl}**	**EC µS/cm**	**OM %**	**Total N %**	**Assimilable Phosphorus ppm**
	Sand %	**Silt %**	**Clay %**						
Sol	71	16	13	6,90	6,68	149	0,6	0,03	0,5
Biochar	-	-	-	9,22	8,96	6210	57,8	0,04	78,3
Compost	-	-	-	7,49	7,15	788	21,7	0,41	156,3

Table 2 : Major elements in percentage (%) of soil, biochar and compost samples.

Samples	**Al_2O_3**	**Fe_2O_3**	**SiO_2**	**K_2O**	**TiO_2**	**CaO**	**NaO**	**MgO**	**P_2O_5**	**LOI**	**CIA**	**MIA**	**Total**
Sol	1,20	0,79	96,92	0,18	0,35	-	-	-	-	0,80	87,1	74,2	100,23
Biochar	0,23	0,16	8,21	8,84	-	0,91	0,56	1,20	1,33	76,73	-	-	99,68
Compost	4,49	1,54	75,74	1,75	0,35	1,15	0,27	0,45	0,51	13,88	-	-	100,18

Table 3 : Trace metals in soil, biochar and compost samples.

Samples	**Cr ppm**	**Mn ppm**	**Co ppm**	**Ni ppm**	**Cu ppm**	**Zn ppm**	**Se ppm**	**Cd ppm**	**Pb ppm**
Sol	32,5	176,0	4,7	10,7	7,8	4,5	0,3	0,0	4,3
Biochar	18,3	70,9	0,4	2,0	14,3	45,5	0,2	0,0	0,9
Compost	40,8	345,7	4,8	9,2	14,9	53,4	0,7	0,1	7,0

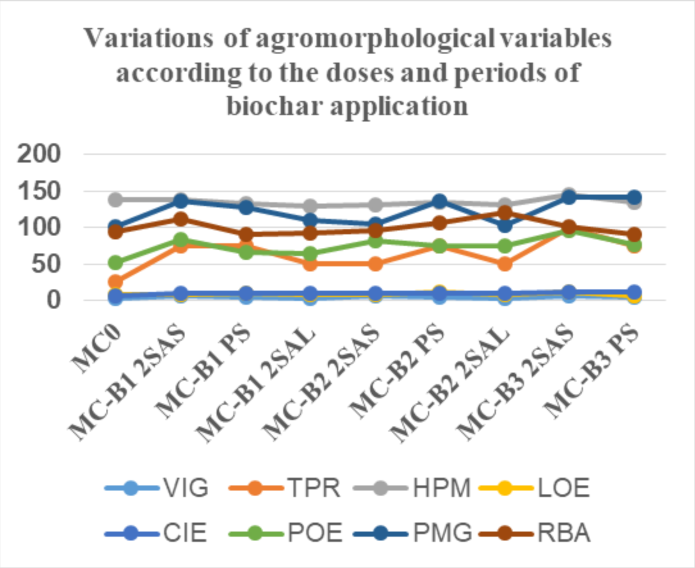

Figure 2: Effect of biochar on agromorphological variables as a function of doses and application periods.

Table 4: Agromorphological variables as a function of fertiliser application rates and periods.

Treatments	**Input period**	**Agronomic variables**							
		VIG	TPR	HPM	LOE	CIE	POE	PMG	RBA
Témoin	MC0	3	25	138,3	9	6,5	51,9	102	93,9
Treatment with 5t/ha of biochar	MC-B1 2SAS	7	75	137,3	9	10	83,3	136,3	111,4
	MC-B1 PS	5	75	132	9,5	10,8	66,6	128,2	91,5
	MC-B1 2SAL	3	50	128,7	8,7	9,6	64,7	110,4	92,5
	Average MC-B1	**5**	**66,7**	**132,7**	**9,1**	**10,1**	**71,5**	**125**	**98,5**
Treatment with 7.5t/ha of biochar	MC-B2 2SAS	7	50	131,7	9,1	10,1	82,6	105,3	96,8
	MC-B2 PS	5	75	133,7	11	10,6	74,8	137,1	106,2
	MC-B2 2SAL	3	50	131,7	9	10	74,9	103,1	121,3
	Average MC-B2	**5**	**58,3**	**132,4**	**9,7**	**10,2**	**77,4**	**115,2**	**108,1**
Treatment with 10t/ha of biochar	MC-B3 2SAS	7	100	145	11	12	95,1	142,3	101,2
	MC-B3 PS	5	75	134	7	11,4	76,3	141,4	91,3
	MC-B3 2SAL	3	75	138,3	7	10,8	68,9	113,5	105,1
	Average MC-B3	**5**	**83,3**	**139,1**	**8,3**	**11,4**	**80,1**	**132,4**	**99,2**
Treatment with 5t/ha biochar+5t/ha compost	MC-BC1 2SAS	7	75	136,7	6,5	7,4	74,6	92,6	109,4
	MC-BC1 PS	5	25	125,3	6	10	62,3	167,2	112,7
	MC-BC1 2SAL	3	25	95	5	8,7	62,4	161,3	58,6
	Average MC-BC1	**5**	**41,7**	**119**	**5,8**	**8,7**	**66,4**	**140,4**	**93,6**
Treatment wit	MC-BC2 2SAS	7	75	141,7	8,5	9,3	70,9	178,1	108,7

	MC-BC2 PS	5	75	141,7	8,8	8,5	66,5	165,6	89,5
	MC-BC2 2SAL	3	25	128,3	5	6	64,1	168,5	133,7
	Average MC-BC2	**5**	**58,3**	**137,2**	**7,4**	**7,9**	**67,2**	**170,7**	**110,6**
Treatment with 10t/ha biochar+5t/ha compost	MC-BC3 2SAS	7	100	137,3	11,2	8,9	96,3	190,9	126
	MC-BC3 PS	5	100	116,7	7,7	7,7	78,8	179,9	69,3
	MC-BC3 2SAL	3	75	117,7	5,3	8,9	75,1	191	84,3
	Average MC-BC3	**5**	**91,7**	**123,9**	**8,1**	**8,5**	**83,4**	**187,3**	**93,2**

VIG: Plant vigour 15 days after emergence; TPR: Rate of plants harvested; HPM: Plant height at maturity; LOE: Ear length; CIE: Ear circumference; POE: Ear weight; PMG: Thousand seed weight; RBA: Above-ground biomass yield.

Table 5: Correlation matrix between the different agromorphological variables.

Variables	**VIG**	**TPR**	**HPM**	**LOE**	**CIE**	**POE**	**PMG**	**RBA**
VIG	1							
TPR	,552*	1						
HPM	,471*	,389	1					
LOE	,481*	,502*	,609**	1				
CIE	,267	,378	,232	,407	1			
POE	,673**	,748**	,282	,503*	,428	1		
PMG	,078	,236	-,296	-,192	-,145	,196	1	
RBA	,230	-,031	,597**	,223	-,036	,226	-,094	1

*** :** The correlation is significant at the p<0.05 level.; **** :** The correlation is highly significant at the p<0.01 level.

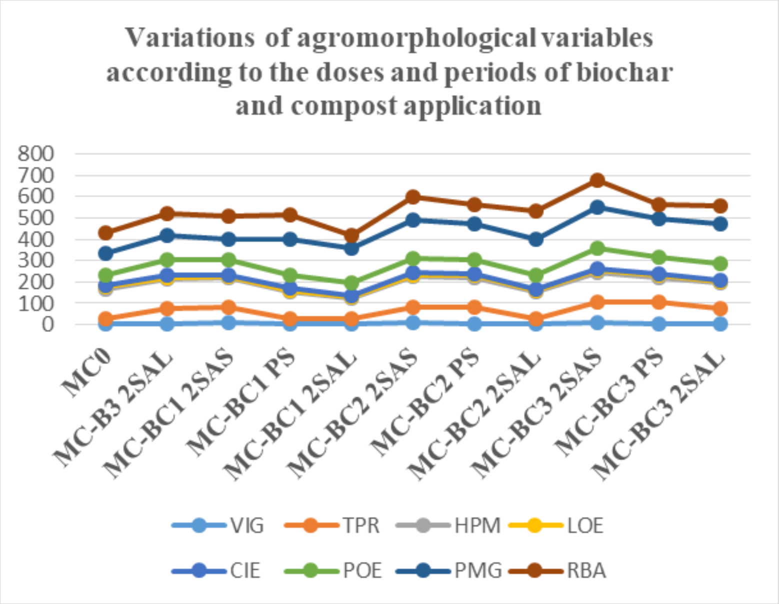

Figure 3: Effect of biochar combined with compost on agromorphological variables as a function of application rates and periods.

DISCUSSION

The soil studied and used for the pot trial in a controlled environment was a sandy-loam type, poor in organic matter and had low levels of total nitrogen and available phosphorus. These results were demonstrated in the work of (Djetoguem, 2015) who concluded that these soils have overall poor to very poor fertility. This low fertility would be linked to an overexploitation of the soil with nutrients taken by the plants without compensatory restitution. In addition, this soil has a very high chemical deterioration index (87.1) and a significant mineralogical deterioration index (74.2). These indices can be explained by the very low content of Al2O3, Fe2O3, P2O5, some of which are even below the sole determination (Al2O3, Fe2O3, P2O5). Thus, the type of soil and the weathering indices seem to be correlated with the more sandy (71%) and clay-poor (13%) grain size. This notable poverty in clay also explains the significant poverty in oxides (Al2O3, Fe2O3, P2O5). Cheverry and Fromaget (1970) in Bahouro et al., (2022) also described these soils as being very leached, which is consistent with the present results. The biochar and compost used had high levels of available phosphorus (78.3 and 156.3 ppm) and organic matter (57.8 and 21.7%). Similar results, especially on biochar, were reported by Léle (2016), Guangming et al. (2013), Mounirou (2022) and Mayola et al. (2017).

In the present study, plant vigour (VIG) showed better plant behaviours irrespective of the dose at 2SAS; seedling supply (PS) indicates lower and lesser vigour (VIG = 5); at 2SAL, plants show lower vigour (VIG = 3) than others. The decreasing vigour from 2SAS to 2SAL such that 2SAS>PS>2SAL could be explained by the input that would have progressively released nutrients to the plants; the more timely the input, the more nutrients are released and available to the plants for their growth, which promotes their development (Diallo, 2005). Similarly, the vigour of the plants observed in the treatments that received a 2SAS application reflected a high rate of harvested plants. Moreover, the highly significant correlation of vigour to ear weight can be explained by the fact that vigorous plants produced better ears. Hence the significant and positive correlation at the 5% threshold of VIG to the variables TPR (r = 0.552), LOE (r = 0.481), POE (r = 0.673) and HPM (r = 0.471).

Harvested plant rates (HPR) were in all cases higher in 2SAS treatments (50-100%), followed by PS treatments (25-100%) and finally 2SAL treatments (25-75%) compared to the control (HPR = 25%). These rates correlated positively and significantly (at the 5% threshold) with plant vigour (r = 0.552) and could be explained by the fact that vigour at emergence, which is itself dependent on the period of fertiliser application, influenced growth, which allowed the plants to develop until maturity (Ilunga et al., 2018).

Plant height at maturity evolved irregularly and was not dose-dependent. Overall, plant heights were greater in the 2SAS inputs than in the PS and 2SAL inputs, regardless of treatment. However, it was noted that plant height at maturity was greater in the control (138.3 cm) than in most of the amended treatments. Its positive correlation with plant vigour at the 5% threshold (r = 0.471) would indicate that it would be related to it.

The values for ear length indicated that the amendments did not influence ear size as the control indicates a higher value than in other amended treatments. However, the 2 SAS and PS inputs showed higher values than 2SAL. On the other hand, the positive and significant correlation at 5% between LOE and VIG (r = 0.481) and TPR (r = 0.496) and the highly significant positive correlation (only 1%) with HPM (r = 0.606) would indicate that the more vigorous and taller the plant, the taller the ear. The vigour and height of the plant would influence the size of the ear (Ilunga et al., 2018).

The circumference of the ear indicates its size. It is also a determining factor influencing the yield. In this case, the amendment considerably improved the size of the ear compared to the control (6.5 cm), regardless of the treatment and the application period. This improvement would be due to the nutrient inputs from the fertiliser and/or improver products, i.e. biochar and compost. Diallo (2005) and Maman and Mason (2013) had shown that organic inputs would improve soil quality through the release of chemical plant nutrients.

The weight of the ear is a variable that helps to assess yield. The trial showed that at all rates and times, ear weight was significantly improved compared to the control. However, it strongly correlated with plant vigour (r = 0.673) and the rate of harvested plants (r = 0.748). This positive correlation with the length of the ear (r = 503) would indicate that the pots having received a 2SAS contribution influenced the growth of the plants; these plants being vigorous consequently produced longer ears and more important in weight from where these correlations.

The thousand-seed weights measured showed that the amendments significantly improved grain yield in terms of weight compared to the control, regardless of the application rate and period. It could be seen that the thousand-seed weight is not a function of treatment or application period. It did not show any significant correlation with the other agromorphological variables.

Above-ground biomass yield was also variable and did not closely related to treatment or application periods. However, it’s positive and highly significant correlation at the 1% threshold (r = 0.597) would indicate that the greater the plant height, the greater the biomass (Ilunga et al., 2018).

Based on the average of the key performance and yield indicator variables of plant vigour at emergence, harvested (opened) plant rate, ear circumference (size) and thousand kernel weight, the 10t/ha biochar dose alone (MC-B1) and the 10t/ha biochar + 5t/ha compost dose (MC-BC1) are better. For these better doses, this could be explained by the quantity applied improving the chemical quality of the soil and releasing enough chemical elements (Diallo, 2005; Maman and Mason, 2013) that contributed to good soil productivity (Lehman et al., 2006; Major et al., 2010; Uzoma et al., 2011; Somda et al., 2017) compared to the control. These results are consistent with those obtained by Diatité et al. (2020) who found that 10t/ha of organic fertiliser gave better results than 5t/ha on the chemical properties of the soil which has a direct effect on soil productivity. For the best application period, we can base ourselves on the vigour of the plant at emergence, which is higher at 2SAS (VIG = 7) than at other periods (PS = 5 and 2SAL = 3). Furthermore, vigour is significantly and positively correlated at a threshold of 5% with the TPR variable (r = 0.552). Thus, a pre-sowing amendment would favour the growth and development of the plant. These results are in line with those of Kimuni et al. (2014) who showed that a contribution of litter 15 days before sowing underwent an effective decomposition under the effect of microorganisms attached to the crop substrate (bacteria, fungi) and this would have allowed the release of essential nutrients for plant growth and consequently production. This result is also in line with the work of several authors who have worked in the same direction. They have shown in most cases that the further away from emergence (after emergence) the fertiliser is applied (organic, organo-mineral or mineral), the less satisfactory the result; application before sowing or at sowing for organic amendments gives better results (Gomgnimbou et al., 2019; Miningou et al., 2020; Deluca et al., 2009).

These results are probably correlated with the chemical properties of biochar and compost, which have high phosphorus and organic matter contents and which have improved the chemical properties of the soil used here. Indeed, several authors (Wang et al., 2018; Kamman et al., 2011) have shown that the conversion of biomass into biochar increases the soluble phosphorus content and the potassium concentration of the plant, which plays a very important role in plant growth and production.

Conclusion

The soil studied and used for the controlled trial is a sandy-silt soil with low organic matter, nitrogen and phosphorus content. The chemical and mineralogical weathering indices are high. The use of biochar alone or combined with compost had a positive effect on soil productivity compared to the control. The doses of 10t/ha biochar alone and 10t/ha biochar + 5t/ha compost gave better results compared to the other doses and to the control and therefore are the best doses. With regard to the timing of fertiliser application, the application two weeks before sowing gave better results than the application at sowing and the application two weeks after emergence. These better formulas can be demonstrated in real life or on-farm.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

BA is the corresponding author. ND, DK, BS and AD contributed through reading this document and making observations for its improvement. NJP and AH are the supervisors of this thesis.

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