Vol. 11(1), pp. 17-29, January-March 2020
DOI: 10.5897/JSSEM2019.0798
Articles Number: 393549D63243
ISSN: 2141-2391

http://www.academicjournals.org/JSSEM

Journal of Soil Science and Environmental Management

Full Length Research Paper

Use of charcoal (biochar) to enhance tropical soil fertility: A case of Masako in Democratic Republic of Congo

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Received 5 December 2019; Accepted 10 February 2020

Soil fertility transience in the region of Masako in Democratic Republic (RD) of Congo remains a major challenge to sustainable agricultural production. Recently, biochar application as soil amendment has attracted attention of the people across the world owing to its potential to improve soil physicochemical properties, crop yield and carbon sequestration into the soil. A study was conducted in Masako to analyze the use of charcoal (biochar) as soil amendment and assess its effects on soil chemical performance and some biophysical parameters of maize crop. The experiment was set up using randomized complete block design with three replications of three treatments comprising ½ kg of sieved (small-sized particulate) charcoal per m^2 (C_1), 1 kg of sieved charcoal per m^2 (C_2) and control group without charcoal (C_0). Data were subjected to analysis of variance, Pearson's phenotypic correlation and regression analyses using genstat 12th edition. The results of the analysis of variance showed non-significant variation for most physicochemical properties of soil and maize phenotypic traits, indicating that treatments had the same effects on soil composition suggesting that there was no clear impact of charcoal amendment as applied except for phosphorus content and collar diameter of the maize crop which were significantly ($P \leq 0.047$ and $P \leq 0.043$ respectively) influenced by the treatments. The results indicated that biochar improved the soil phosphorus availability by up to 72% as accounted for by the linear contribution of the treatment C_2 indicating that biochar could be recommended for use in soil with low level of phosphorous.

Key words: Charcoal, tropical soil fertility, Democratic Republic of Congo, *Zea* mays.

INTRODUCTION

Cultivable soils of Masako in DR Congo have always very transient fertility, a context intensified by cropping systems in the area and yet, agriculture remains the main activity for producing food and generating income for the majority of farming population (Tanzito et al., 2009). In addition, socioeconomic, ecological, climatic and

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environmental issues such as soil erosion and routine agricultural calendar disruption, occurring in the country in general and particularly in the locality have been associated with the current agricultural system. As a result, soil fertility issues have emerged as a hindrance to sustainable development as well as to improved living condition of the population in this area (D'Haene, 2015). Yields obtained by peasants through slash and burn farming systems are usually gradually declining as of the second land cultivation, which therefore has hindered continuous growing of crops on the same piece of the farmland (Steiner et al., 2009). Moreover, adoption of semi improved agricultural practices such as agroforestry, mixed cropping, strip cropping and organic amendment in the region did not provide expected results on soil fertility status. This current soil fertility decrease was reported to be the result of rapid mineralization of initial organic matter and the uptake of soil nutrients by growing plants, much as the climate in the region is equatorial-like climatic conditions (Upoki, 2001; Mikwa, 2012). It is therefore the rapid mineralization of organic matter resulting into soil acidification after clearing of forests and the continuous farming which explain the low fertility levels of many tropical soils, including this region (Steiner et al., 2009; Solia, 2016).

Researches have shown that several tropical soil types particularly those severely weathered such as those of Masako (oxisols, ultisols) suffer from some specific problems such as acidity, phosphorus fixation, aluminium and manganese toxicity, low cation exchange capacity (CEC), low base saturation and low soil organic matter contents which undermine optimal crop production (Kang and Tripathi, 1992; Sanchez and Logan, 1992; Costa et al., 2004; Fontes and Alleoni, 2006; Verheye, 2009; D'Haene, 2015).

Nevertheless, it is worth noting that in that area, crops growing on lands with old charcoal oven performed more vigorous than those raised on the normal soils without charcoal (Steiner et al., 2007). This particularity of biological expression of crops on former sites of charcoal burning often spread as small isles over farmlands could be attributed to a number of factors. First, it could be due to the fact that part of ashes derived from incineration, with high nutrients content directly usable by plants are recovered by the crops thus accounting for the increased yield (Steiner et al., 2007). Despite of this benefit of the ashes, Renck and Lehmann (2004) have reported that highly soluble components of the ashes are leached and not recovered by the plant. The role of ashes in plant nutrition could explain the high crop yield during the first crop cycle of slash and burn system (Sanchez and Logan, 1992; Verheye, 2009). Second, charcoal in particulate forms not soluble, buried in the soil during different preparatory works of cultivation improves adsorbent properties of soil (charcoal adsorption surface around 300 sq. $m.g^{-1}$ according to Lefebvre, 2010). Thus nutritional elements would be easily adsorbed and retained in the soil to the benefit of cultivated plants during the next planting season (Lehmann et al., 2006; Lehmann and Joseph, 2009). Consequently, this process would slow natural decline of fertility and confer a quite sustainable characteristic to crop growing on the same piece of land (Steiner et al., 2009; Husk and Major, 2010). However, the soil depth exploited by crop roots remains limited (20 cm) in the region due to common practice of sowings crops' seeds on unploughed lands (FAO, 2003; Alongo et al., 2013). Thus, soil fertility brevity in Masako and in the whole region around Masako constitutes a major challenge to be taken up to claim an agricultural production improvement as well as living standards of local peasants. Therefore, charcoal valorization to enhance soil fertility in Masako turns out to be justified and relevant and deserves to be studied, given that nutrient intake and important adsorbent properties were proven and well documented in literature (Lehmann et al., 2006; Lehmann and Joseph, 2009). In addition, environmental benefits are reported to be linked to soil charcoal amendments such as sustainable storage of carbon in the soil (direct benefit) and forest resources preservation through human pressure decrease on cropping land by recapitalizing nutrient stocks and reducing length of forest fallows (indirect benefit) (Mensah and Frimpong, 2018; Rawat et al., 2019). However, biochar research is a recent development in DR Congo and so, there is a paucity of information regarding its effects on soil properties and crop growth as well as crop yield in DR Congo, especially in Masako forest region. A study by Nyami et al. (2016) reported that biochar in combination with NKP amendment improved soil phosphorus availability in Kinshasa, DR Congo. It was upon this background that the study was conducted to assess the applicability of charcoal as soil amendment in this location. The goal of the study was to contribute towards enriching soil fertility through utilization of charcoal amendment in the form of "biochar"[1]by minimizing the loss of local mineral nutrient through its adsorbent properties and making it available to crops and so foster endogenous fertilization. The results of the study could provide to peasants a scientific-based tool of sensitization about substantial technique of reducing carbon dioxide emission in the atmosphere while enhancing their agricultural yield. To achieve this goal, the following specific objectives were set: (1) to assess the effects of charcoal amendment on maize (*zea mays* L.) crop yield in Masako, DR Congo and, (2) to evaluate the impact of charcoal application on soil mineral nutrient content.

MATERIALS AND METHODS

Geographical location of the study area

This study was conducted in Masako, a small village with a forest

[1] Charcoal ground in fine particles

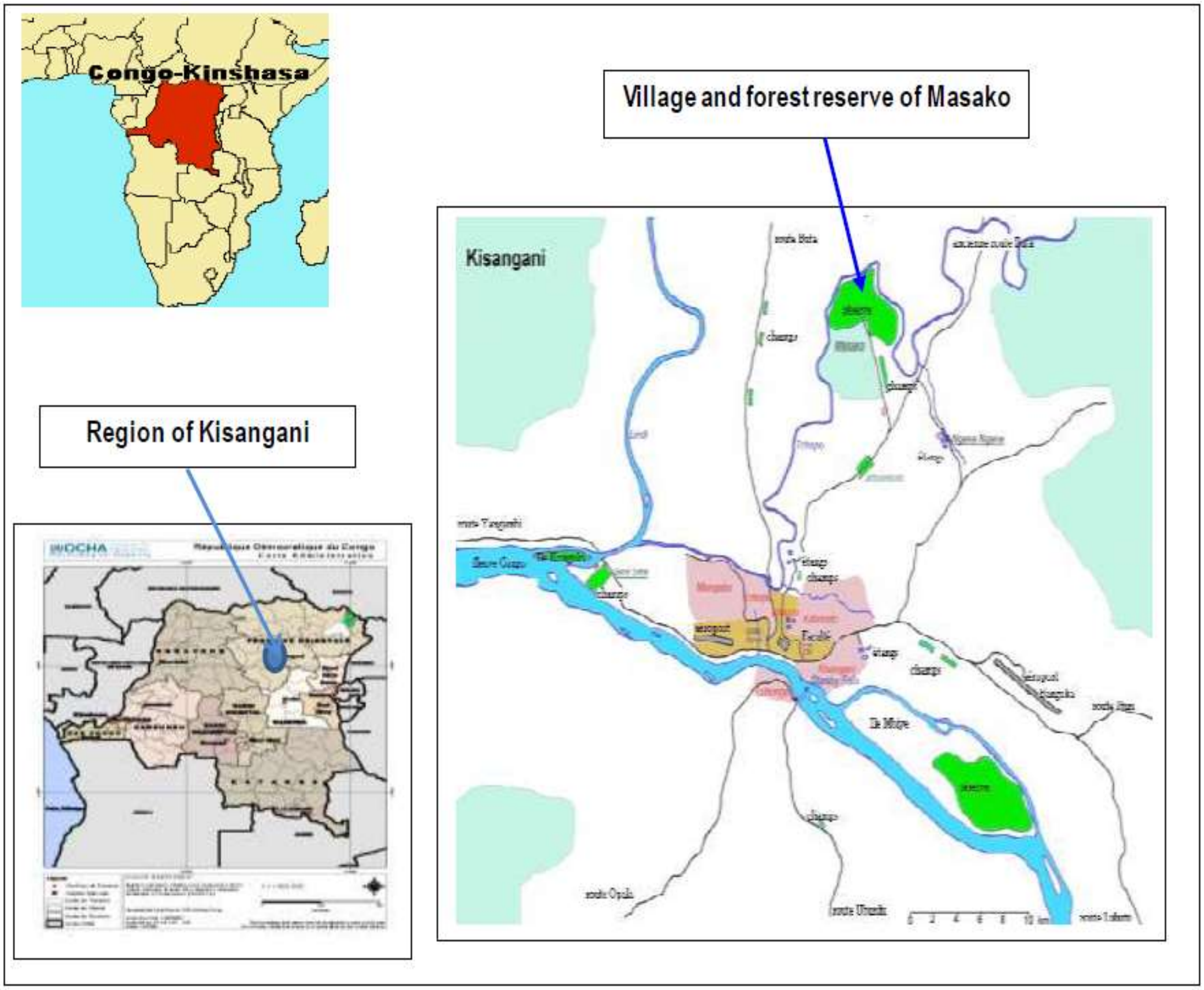

Figure 1. (a) The DR Congo; (b) Kisangani city and region; (c) village of Masako and its forest reserve.
Source: a & b: UNOPS/PACO (UNOPS: United Nations Office for Project Services. PACO: Projet d'Appui à la Coordination des observateurs aux élections de 2006 en RD Congo), 2006; c: UNOCHA (UNOCHA: United Nations Office for the Coordination of Humanitarian Affairs), 2009.

reserve located at 14 km on the old road of Buta, northeast of Kisangani city. Kisangani is the main city of the former Eastern province (today province of Tshopo) in the northeastern Democratic Republic of the Congo (Figure 1 a, b and c).

The particular relevance driving the choice of this study area is the fact that it was one of the multiple forest reserves of the country. The area occupies up to 2,105 ha of natural forest reserve (Mikwa, 2012). The average geographic coordinates of the area are: 0°36' latitude north, 25°13' longitude east, with an altitude varying between 376 and 470 m above sea level (Masl).

Masako and surrounding areas are under the climatic conditions of the city of Kisangani, an equatorial-like climate, even though the location is sometimes subject to the influence of the vegetation cover that prevails in the site. In fact, the region of Kisangani is located in the bioclimatic zone of evergreen tropical rainforest. The zone is characterized by Af_1-like climate according to the classification of kôppen-Geiger (Upoki, 2001: Thienpondt, 2016; Posho et al., 2017). The temperature of the coldest month is above 18°C and the rainfall of the driest month is above 60 mm. Generally, the temperature of 25.3°C in March and 23.5°C in August were recorded with a yearly average of 24.4°C. The relative humidity has been reported to vary between 79.1% in February and 87.3% in July with an annual average of 84.0%. The location has been reported to experience abundant precipitations distributed throughout the year with an annual average of 1782.7 mm, two equatorial maxima around October and April and two solsticial minima around January and July. The annual average number of rainy days stood at about 155. However, with climatic perturbations observed currently at the global level, the region experienced the occurrence of small dry season around January and June and the insolation was quite high in the region (Upoki, 2001; Van de Perre et al., 2019). The yearly average turned around 5.4 h per day, with high intensity between 10 H and 14 H especially during the driest months (January) reaching 1945 h per year, accounting for 45%

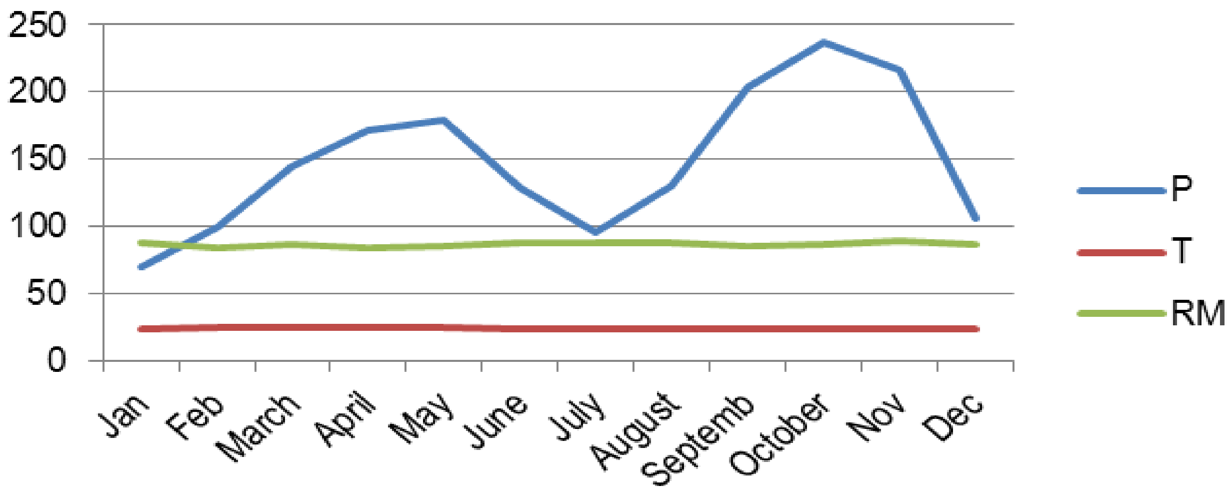

Figure 2. General trend of climatic factors in the region of Kisangani in 2010. P = precipitation (mm), T = temperature (°C) and RM = relative moisture (%).
Source: Meteorological station of the international airport of Kisangani-Bangboka.

of total radiation. In contrast, in some months it declines up to 36%. Figure 2 depicts the average trend of rainfall, heat and moisture prevailing in the region over the year 2010.

Soils in the region of Kisangani like all those in equatorial climates are relatively poor (Kombele, 2002; Thienpondt, 2016). They are mostly oxisols (ferralsols according to FAO classification), with low humus content (average rate of carbon and organic nitrogen 1.5 and 0.1 %), predominately sandy (sand average rate: 70.1%, silt: 6.5%, clay: 23.4%) and controlled by kaolinite in the clayey fraction. They are acid soils (average water pH and KCl 1N, respectively at 4.9 and 3.7) with low cation exchange capacity (CEC: < 7 meq/100g).

The vegetation in the area consisted of primary, secondary forest and fallow lands; with species like *Gilbertiodendron dewevrei, Polyanlthia mavelolens, strombosia glaucescens*, *Pycnanthus angolensis, Zanthoxelon gilletii, Cynometra hankey, Petersianthus macrocarpum, Funtumia elastica, Uapaca guineensis, Lannea welwitschii, Ricinodendron heudelotii, Sterculia bequertii,* and *Musanga cecropioides, Afromomum laurentii* and so many other shrubby and grass species especially *Panicum maximum* (Mikwa, 2012; Nkongolo and Bapeamoni, 2018). The majority of residents is farm operators practicing mainly slash and burn and mixed cropping system. Maize, cassava and paddy rice account among the main crops produced and charcoal making constitutes one of the predominant activities of peasants. Unfortunately, according to all likelihood, this predominant cropping system seems imposed by ecological, climatic and physical conditions of the environment as well as the economic level of peasants. So, it seemed hard to local farmers to give up this predominant cropping system and woefully, they were forced to be doing with.

Data collection process

Data collection for this study was carried out in two sequencing steps: For the first step, two successive field trials were conducted with charcoal soil amendment as the treatment in order to measure its direct impact on maize crop yield and a control trial on the same land without charcoal application to assess its following effects. The two trials covered a period of 8 months, 4 months for each from 14th December 2009 to 14th April 2010 and again from 24th April 2010 to 20th August 2010. Secondly, by the completion of the experimental trials, one day after the second harvest (on 21st August 2010), soil samples were collected on the experimental site in two different depths, at 0-10 cm and 10-20 cm, to quantify total organic carbon (TOC), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), charcoal content and the hydrogen potential (pH) of the soil. Due to resource limitations which did not allow us to carry out soil analyses before the experiment setting up, the present secondary data of the average soil nutrient content in the region was used as reference to draw conclusion regarding soil mineral composition and fertility after the trials.

The testing crop used was the maize (*Zea mays* L.), a local landrace with white grain, bought on the local market from peasants. Maize crop was used in the study because it was one of the predominantly grown crops by the farmers and it was one of the crops whose production was supported by the ecological and climatic conditions as well as the production system of the region.

Charcoal handling

The fertilizing material (amendment) used in the experiment was the charcoal (biochar) commonly called “Makala” in the region acquired from local peasants. The charcoal was pounded into smaller particles (Lehmann et al., 2006; Lehmann and Joseph, 2009) using a wooden mortar and pestle and sieved using a 0.5 mm wire mesh fixed between a rectangular wooden frame prior to the application into the soil (Figure 3a and b).

The land for the experiment was prepared through forest fallow clearing and logging followed by manual tillage with hand hoe at 20 cm average depth and picketing, delineation of experimental plots and harrowing. The final operation of land preparation (shallow tillage) also served to integrate (bury) the biochar into the soil following manual spreading on the soil surface of the experimental plots.

The planting of maize seeds, soaked in fresh water at ambient temperature 24 h before, took place on plots covered with ashes derived from the incineration of dried biomass amounts, essentially made up of batches of chaffs and tree lops, gathered and incinerated on experimental units due to 1 kg of dry biomass per square metre, that is, 25 kg per 25m^2 of plot (Figure 4a, b and c).

(a) (b)

Figure 3. Charcoal pounding (a) and sieving process (b).

(a) (b) (c)

Figure 4. (a) Biomass gathering and weighing; (b) incineration on plots, and (c) maize planting.

The agronomic practices applied to the experimental field consisted of row replanting, crop spacing, mulching and weeding. Supplementary irrigation by watering to complement rainfall deficiency at the beginning of the experiments followed. The preparation of seedbed for the second trial consisted of a minimum tillage followed by planting. As a whole, the agronomic practices were implemented following the same practices as for the first trial; however, this time no supplementary irrigation was done because of the onset of the rain.

Experimental design

The experiment was set up using a mono factorial randomized complete block design (RCBD) with three replications comprising of three treatments. Each experimental unit measuring 5 m x 5 m (25 m^2) in size was separated by a 1 m distance from one another and the three blocks were 1.5 m apart. On each experimental plot one to two maize seeds were planted per hole spaced at 0.5 m x 1 m. Under this spacing regime, each experimental unit consisted of 5 rows each with 8 planting stations (hills), a total of 40 holes per experimental unit and ± 60 plants per plot (Figure 5). The periphery of the entire experimental site was cleared to provide a 2 m width space to minimize border effect (Figure 5).

The studied factor was the charcoal, used as amendment to enrich crop growing substrate with three levels: C_1 = ½ kg of sieved (small-sized particulate) charcoal per m^2, C_2 = 1 kg of sieved charcoal per m^2 and C_0 = control group without charcoal.

Data collection process

Data collection was started 21 days after planting (DAP) on 25 randomly selected and tagged maize plants from each of the experimental plots. Various parameters including plant growth rate (cm/week), plant height (total average in cm), root collar diameter (cm), number of ears /plant and the yield parameters such as number of ears per plant, and grain yield per plot were measured and recorded. Height was successively measured at a weekly interval using a tape measure for four consecutive weeks. The plant height was measured as the distance between the root collar and the collar of the last developing leaf using Chinese made measuring tape. The growth rate was computed by subtracting the initial plant height from the final plant height and dividing by the duration taken to attain the plant height (H_2-H_1/t), where H_2=final plant height (cm), H_1 initial plant height (cm) and t = the duration plants have taken to attain the final height measurement (weeks). The collar diameter was determined using a vernier caliper (China, Perel) provided with mm and cm graduation. The number of ears per plant and plot were determined through manual counting.

Data on the average yield was collected at the physiological maturity of the maize at the time when the whole crops on the field displayed quite more or less dry guise. The average yield was estimated by weighing dry ears with husks using a Chinese-made balance with 0.1 graduation scale measuring up to 22 kg mass. The measurements were first expressed in g/plant and later converted into tons/ha of maize grain according to the conversion reference provided by Songbo (2003) who reported that 100 kg of dried ears

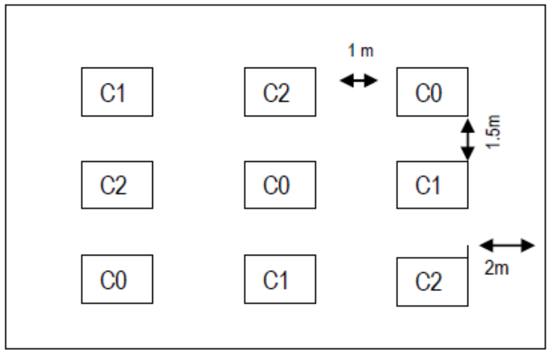

Figure 5. Research design and field layout.

Table 1. Analysis of variance for the effect of the treatments on the maize plant growth and yield parameters.

Source of variation	D.f	N.E	G.R	C.D	H	Yield
Trial	1	0.74**	0.21**	2.90***	0.20*	1.94*
Trial/block	4	0.02	0.01	0.01	0.01	0.18
Treatment	2	0.05	0.03	0.05*	0.03	0.40
Residual	10	0.03	0.03	0.01	0.03	0.21
CV (%)		14.9	7.9	4.1	7.9	11.5

***, **, * Significant at 0.001; 0.01, and 0.05 probability levels, respectively, N.E = Number of ears per plant, G.R = Growth rate (in cm/day), C.D = Collar diameter in cm/plant, H =Height in meter per plant, Yield = yield in t/ha of grain, D.f = Degree of freedom, CV = Coefficient of variation.

with husk provide 40 to 50% of grain.

One day after harvesting maize from the second trial, composite soil samples were collected using auger at two different soil depths of 0-10 and 10-20 cm from each of the experimental units and kept separate. These two soil depths are the most used soil layers by crop roots (Alongo et al., 2013; FAO, 2003). The composite sampling was carried out by the collection and merger of soil samples from 9 different sites from each plot; that is, from 8 spots along the perimeters one meter deep from the edge of experimental unit and one in the middle These samples were then bulked per depth to obtain two composite samples of 50 g each per experimental unit, which made a total of 18 samples comprising of 9 for 0-10 cm soil depth and another 9 for 10-20 cm soil depth. The samples were sent for analysis to the Provincial Center of Land Analysis of Hulpe in Belgium for basic fertility parameters namely, pH (KCL), total organic carbon (through ash drying), phosphorus (P), potassium (K), magnesium (Mg) and calcium (Ca) (Ammonia acetate + EDTA at pH 4.65).

Data analysis

Analysis of variance was performed using Genstat (12th version) to estimate the amount of variability for the biological traits. Means were separated using the Fisher's protected least significant difference (Lsd) at 0.05% significance level (Ibanda et al., 2018). Pearson's phenotypic correlation estimates were computed for the studied biophysical parameters. The regression analysis was conducted using MS Excel software to determine the proportion of variation in the number of ears accounted for by phosphorus and also to determine the proportion of variation in phosphorus content accounted by the charcoal treatments. R statistical package (Version 3.6.1, 2019-07-05) was used to plot the graphs.

RESULTS AND DISCUSSION

Analysis of variance of growth and yield parameters of the maize plants

The results of analysis of variance showed non-significant differences among treatments for all biological parameters measured except for the collar diameter which showed significant ($P \leq 0.043$) difference among treatments (Table 1). This indicates that in general, treatments had the same effects on performance of maize suggesting that biochar did not provide evidence of its effect in the improvement of maize crop biological performance. In contrast to these findings, several studies reported that biochar offered the potential to enhance soil quality and hence improved the plant height, stem girth and dry matter yields in many crop including maize (Lehmann et al., 2006; Lehmann and Joseph, 2009; Mensah and Frimpong, 2018). The significant variation observed for collar diameter suggested a probable positive impact of charcoal amendment on this trait.

The trial had highly significant ($P \leq 0.0003$) effect for collar diameter and significant ($P \leq 0.003$, 0.008, 0.03 and 0.03) effects for number of ears/plant, growth rate, height and yield, respectively. This suggested that the difference in climatic conditions and spatial variability of soil as well as nutrient loss due to plant uptake and utilization in plants growth and yield improvement was

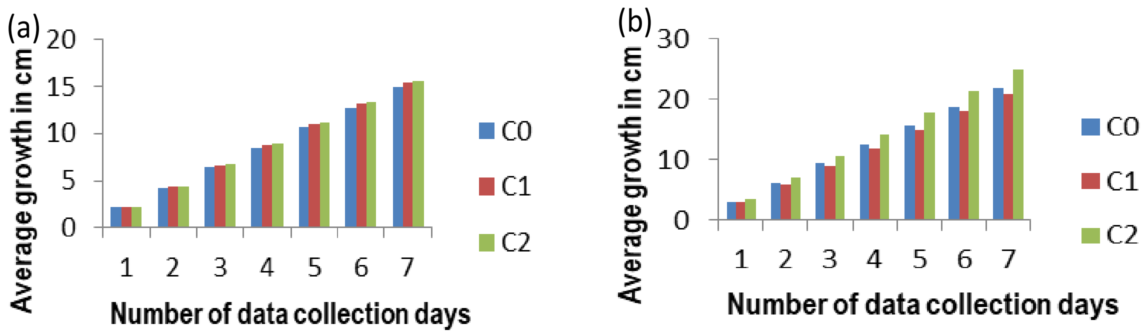

Figure 6. Average trend of crop growth over 52 days. a = first trial; b = second trial.

Table 2. Mean performance of height, collar diameter, average number of ears and grain yield for two trials.

Treatment	Parameter							
	Trial 1				Trial 2			
	H	C.D	N.E	Yield	H	C.D	N.E	Yield
C0	2.20	2.10	1.30	4.10	2.02	2.90	0.94	3.52
C1	2.30	2.04	1.30	4.00	1.90	2.80	0.96	3.60
C2	2.24	2.20	1.60	4.70	2.20	3.00	0.98	3.73
GM	2.22	2.11	1.36	4.26	2.03	2.91	0.96	3.60
LSD (0.05)	0.30	0.28	0.47	13.8	0.44	0.23	0.30	0.76

H =Height in meter per plant, C.D = Collar diameter in cm/plant, N.E = Number of ears per plant, Yield = yield in t/ha of grain, LSD = Least significant differences of means, GM = Grand mean.

significant in the performance of maize between the two trials.

The mean maize growth and yield performance

Growth rate

The mean performance of growth rate showed that the treatment C_2 had a slightly higher growth rate than C_0 and C_1 (2.23 cm/day against 2.21 and 2.13, respectively) in first trial (Figure 6a). In the second trial in contrast, there was a marked gain under C_2 (+13% compared to the control group). However, this was not the case for C_1 where there was a decline of 4.16% compared to the control plot. This could be correlated to the initial soil heterogeneity in nutrients. Nevertheless, in general, the growth rate in the second experiment was slightly better than in the first one (including the control group). This was clearly due to the positive impact related to the abundant rain experienced at the onset of the rain which have boosted the growth of the maize plants (Figure 6b). However, all together, these results are lower (at an average of 2.27 cm per day as a whole) than that which was found by Mugisa, (2005) who achieved an average growth rate of 4.14 cm/day over 56 days without amendment in the same area.

The two graphs indicate that the general trend of growth during the first experiment was almost similar whatever the treatment. Over the second trial, the similarity of trends was maintained even though under C_2, there was a small decrease compared to C_1. However, the declining growth rate observed for the treatment C_1 (1/2 kg of charcoal/sq. metre) against the control group indicated a less positive response of the treatment over the test crop.

Average crop height

The results of the average height showed a small increase in the first trial compared to that of the second (Table 2). During the first experiment, the plant height was not significantly affected by the treatments (2.3 m under C_1 and 2.24 m under C_2). On the other hand, during the second trial, a decrease in height was observed for C_1 treatment compared to the control group. However, the two trials in regards to the average height of both treatments exhibited similar plant heights ranging from 2 to 2.3 m. Bolakonga et al. (2007) found in the same region, an average height of maize crop of 1.3 m while amending the soil with salt of raw ashes derived

Table 3. ANOVA for nutrient content of soil after amendment application into the soil.

Source of variation	d.f.	Ca	K	Mg	P	TOC	PH
Depth	1	4.30*	39.04	4.84	1.00**	0.30*	0.05
Depth/Block	4	0.30	6.83	0.85	0.03	0.02	0.01
Treatment	2	0.80	6.07	0.02	0.09*	0.03	0.02
Residual	10	0.32	4.78	0.07	0.02	0.02	0.01
CV (%)		20.40	28.3	26.9	12.30	10.90	2.70

**, * Significant at 0.01, and 0.05 probability levels, respectively, D.f = degree of freedom, Ca = Calcium mg $100g^{-1}$, K = Potassium mg $100g^{-1}$, Mg = Magnesium mg100 g^{-1}, P = Phosphorus mg $100g^{-1}$, TOC = Total organic carbon in g $100g^{-1}$ of soil, pH = Potential in hydrogen, CV = Coefficient of variation.

from hyacinth (*Eichhornia crassipes* Solms) with 43.58 g of extract equivalent to 25 kg of K_2O/ha and 2.58 m for every 130.74 extract equivalent to 75 kg of K_2O/ha. The last average height was just slightly higher than that achieved through this study under the highest level of charcoal (1 kg/m^2) and could be explained by the difference in the treatments especially the source of the ashes as well as the used research methodology. Although the experiment undertaken by Bolakonga et al. (2007) was conducted in single trial, this height increase could be demonstrated by the high calcium content in *Eichhornia crassipes* Solms which may not be the case of charcoal used in this test. However, the findings of this study were similar to those of Mugisa, (2005) who found an average height of 2.32 m without amendment but quite higher than those of Moussa et al. (2018) in Niger (an average of 1.37 m) with urea and Di-ammonium-phosphate (DAP) mineral fertilizers.

Collar diameter of the maize

The average collar diameters for most of maize plants were more robust during the second trial than the first, reaching up to 3 cm of diameter under C_2, probably due to the differences in climatic conditions (Table 2). Nonetheless, C_1 treatment was shown to be slightly thinner compared to the control group throughout the trial. In contrast, C_2 produced more vigorous plants than the control group throughout the two trials achieving the highest value of 3 cm. These results were similar to those reported by Bolakonga at al. (2007) for the experiments conducted in the same location (using salt of raw ashes derived from hyacinth, *E. crassipes* Solms) where the root collar diameters varied between 2.28 to 2.64 cm, which were far lower than that of Batamoussi et al. (2014) in ferruginous soil and with a chemical treatment (5 cm).

Number of the maize ears

The average number of ears had reduced during the second trial compared to that produced in the first trial (Table 2). While in the first trial average number of ears was above 1 ear per plant, it has declined even to below 1 ear/plant in the second trial (this number was slightly lower than 1 ear/plant). This performance tends to confirm the rapid much-maligned decrease of the potential initial nutrient of soil connected to the first harvest. On the contrary, except for C_1 in the first trial, the average number of ears progressed with the treatment demonstrating a small decrease compared to the control group as well during the first trial as in the second, reaching an average of 1.60 ears per plant under C_2 in the first trial. However, the average number of ears remains around 1 ear per plant, which was quite lower than an average of 1.21 ears found by Nyembo et al. (2014) in the southeast of the country under NPKS and urea mineral fertilizer application.

Yield average

In general, there was good production in the first trial than the second (Table 2). There was a small improvement of yield observed in C_2 compared to the control group over the two experiments (12.8 and 3.6% for the first and the second trial, respectively). The yield deficit between the first and the second trial was 1.1t/ha on average, which represented a decrease of 26.4% for C_0, 12.4% for C_1 and 23.4% for C_2. However, despite yield decline in the second trial, the production in the second experiment still remained quite good with an average of 3.5t/ha of grain yield, an amount quite higher than the usual average yield obtained by the peasants of between 500 and 1500 kg per ha (Songbo, 2003). These findings were in contradiction to those reported by Mugisa (2005) in the same area without amendment who reported a maize yield of 6.1 t/ha on average, but was quite higher than the highest result obtained by Batamoussi et al. (2014) on ferruginous soil with NPK inorganic fertilizers.

Analysis of variance for the nutrient composition of soil

The results of analysis of variance for the nutrient composition of soil showed non-significant differences among treatments for all parameters measured except for the phosphorus which showed significant ($P \leq 0.047$) difference among treatments (Table 3).

Table 4. Nutrient content of soil after amendment.

Treatment	0-10 cm soil depth						10-20 cm soil depth					
	pH	TOC	P	K	Mg	Ca	pH	TOC	P	K	Mg	Ca
C0	3.96	1.08	1.50	7.90	1.52	13.02	3.83	0.50	0.97	5.30	0.70	6.10
C1	3.96	1.76	1.48	9.50	1.54	10.23	3.80	0.60	1.13	7.50	0.43	3.20
C2	3.80	0.92	1.33	10.21	1.55	7.20	3.80	0.60	0.80	6.00	0.40	3.60
GM	3.91	1.26	1.43	9.20	1.54	10.14	3.80	0.52	0.97	6.26	0.50	4.30
LSD (0.05)	0.30	1.55	0.42	5.40	0.88	12.60	0.19	0.25	0.24	5.23	0.28	2.60

Ca = Calcium mg $100g^{-1}$, K = Potassium mg $100g^{-1}$, Mg = Magnesium mg$100g^{-1}$, P = Phosphorus mg $100g^{-1}$, TOC = Total organic carbon in g $100g^{-1}$ of soil, PH = Potential in hydrogen, LSD = Least significant differences of means, GM = Grand mean.

The results in general suggested that treatments had the same effects on the soil composition for most of the parameters measured except the content of the soil in phosphorus, indicating that the biochar increased the soil availability of phosphorus. Similar result was reported by Mensah and Frimpong (2018) in acidic rainforest and coastal savannah soils in Ghana. Kavitha et al. (2018) also reported that the biochar amendment also improves the soil fertility as it facilitates the biochemical cycling of phosphorous. However, the non-significant differences among treatments for most parameters measured could be explained by the low level of amendment applied as it was just a guiding experiment which did not markedly modify soil chemical proprieties. Moreover, reports suggested that the efficacy of biochar application on agricultural environments could be controlled by various factors such as pyrolysis temperature, feed stock, soil type and biotic interactions (Kavitha et al., 2018). The results also indicated that soil depth had significant ($P \leq 0.015, 0.006, 0.013$) effects with respect to the different treatments for the total calcium, phosphorus and organic carbon, respectively (Table 3). This variation could be explained by the difference in initial composition of soils which was not determined prior to the first trial.

Nutrient content of soil after amendment

The results related to the first layer of soil (0-10 cm) showed that the total average pH remained essentially acidic. Paradoxically, this pH level was even slightly higher for the control plots (3.96) than for the treatment C_2 (3.80). This was very low compared to a report by Alongo et al. (2013) who recorded an average pH of 4.7 under grassy fallow in the same area. This finding confirmed the fact that the charcoal amendment did not play a role in the improvement of soil chemical proprieties (Table 4).

The total organic carbon (TOC) showed variation between treated plots and the control, ranging from 0.92 in C_2 to 1.76 in C_1 g*$100g^{-1}$ of the soil sample. The highest value of 1.76 g*100 g^{-1} in our findings was higher than the reported average of 1.3 g*100 g^{-1} in a non-amended soil of grassy fallow (Alongo et al., 2013). The phosphorus (P) ranged from 1.33 in the treatment C_2 to 1.5 in C_0. These values are higher than what was found by Ngeh (1989) in the same weathered context and depth (1.1 mg*100 g^{-1} of P) but lower than that reported by Majaliwa et al. (2015) with an average of 1.37 mg*100 g^{-1} of phosphorus in Kivu. Furthermore, results related to K showed a declined level under untreated plots recorded at 7.9 mg^{*}100 g^{-1} compared to treated plots of 9.5 for C_1 and 10.21 mg*100 g^{-1} of sample for C_2. The results related to K are higher than Dabin, (1985) result's which reported 5 mg*100g-1 of K in the same weathered context and depth. Similarly, the levels of magnesium remained slightly lower (1.52 mg*$100g^{-1}$) for the control plots than for the first treatments (1.54 mg*$100g^{-1}$ of soil) compared to the second treatment (1.55 mg*$100g^{-1}$). Moreover, the amount of calcium were shown to decline on amended plots while it remained higher in untreated soils (13.02 > 10.23> 7.2 mg*100 g^{-1}). However, these results of magnesium and calcium remain lesser compared to those earlier reported by Njib (1987) and Tchienkoua (1987) for the very same weathered and acidic tropical soils (oxisols, ultisols) with 2.8 and 19 mg of Mg and Ca, respectively.

The results related to the second layer of soil (10 and 20 cm) showed that most nutrients remained less abundant than in the shallow layer and were almost halved (Table 4). Soil pH remained at more or less the same level of 3.8, but the organic carbon which was reduced almost by half of that of the superficial layer, of 0.5 g*100 g^{-1} had shown a small increase under C_2 of 0.6 mg*$100g^{-1}$. The concentration of phosphorus ranged from 0.8 for the soil samples from C_2 to 1.13 mg*$100g^{-1}$ in the case of the soil from the treatment C_1. The potassium remained as abundant in amended soils as it was for unamended soil samples.

On the contrary, the magnesium did not show variation in its mass concentration in regards to the treatments, whereas the concentration of calcium recorded a significant reduction by almost 50% of the superficial layer for all the treatments (Figure 7). These results are in line with the findings from several similar studies which reported a halving level of nutrients with increased depth of soil due to leaching of the soil nutrients (Dabin, 1985; Njib, 1987; Tchienkoua, 1987; Ngeh, 1989; Alongo et al.,

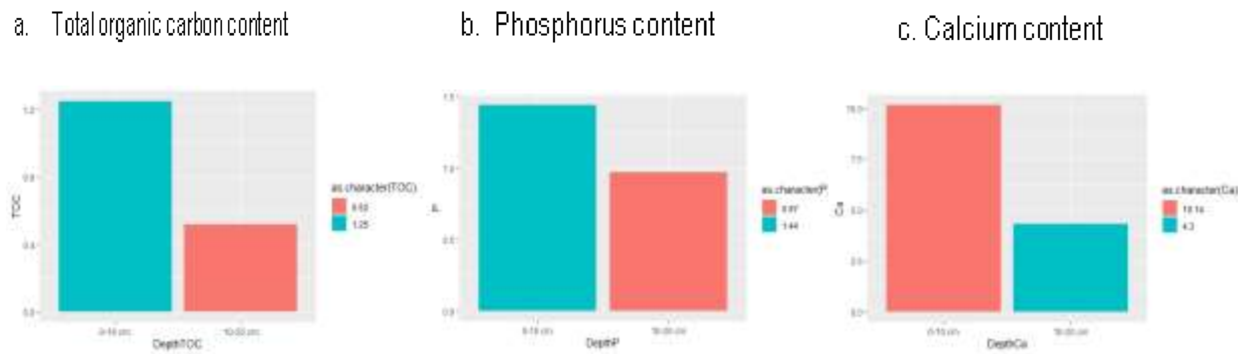

Figure 7. The average of variation of the total carbon content, the phosphorus content and the calcium content in the treatments at the two layers of soil of 0-10 cm and 10- 20 cm depth.

Table 5. Pearson's correlation matrix of maize crop phenotypic traits with the soil phosphorus concentration.

Trait	N.E	G.R	H	P	Yield	C.D
N.E	-					
G.R	-0.42	-				
H	0.49*	0.33	-			
P	0.64**	-0.54*	0.42	-		
Yield	0.75***	-0.30	0.40	0.30	-	
C.D	-0.68**	0.69**	-0.42	-0.84***	-0.42	-

***, **, * Significant at 0.001; 0.01, and 0.05 probability levels, respectively, N.E = Number of ears per plant, G.R = Growth rate (in cm/day), C.D = Collar diameter in cm/plant, Yield = yield in t/ha of ears, H =Height in meter per plant.

2013 and Majaliwa et al., 2015).

Correlation of phenotypic traits with the phosphorus content

The correlation analysis for different biological traits with the phosphorus content showed the phosphorus concentration to be negatively correlated with some biological parameters (Table 5). There was a high significant negative correlation between the phosphorus content and the collar diameter (r = -0.84***). The phosphorus content was also significantly negatively correlated to the growth rate (r = -0.54*), indicating that the increase in phosphorus content would inevitably lead to decreased collar diameter and the rate of growth under the current contents of the other soil nutrients in the soil. In contrast, a positive correlation (r = 0.64**) was found between the number of ears per plant with the phosphorus content indicating that the increase in phosphorus would lead to increased number of ears per plant and could be explained by the fact that phosphorus was reported to play essential role in seed formation and development (Blevins, 1999). Furthermore, the same author also reported that phosphorus also play important role in plant root formation and expansion.

The study also indicated some biological parameters to be significantly and positively correlated among themselves. These included the number of ears per plant which had significant and positive correlations (r = 0.75*** and 0.49*) with yield and height, respectively, suggesting a linear relationship among them. The growth rate and the collar diameter were significantly positively correlated (r = 0.69**). However, some biological parameters were significantly and negatively correlated. For instance, a significant negative correlation (r = -0.68**) was observed between the number of ears per plant and the collar diameter indicating that the increase in numbers of ears would lead to decreased collar diameter. The results of simple linear regression analysis to predict the overall contribution of phosphorus content to the number of ears was shown to be significant ($P \leq 0.004$) with 40% (R^2) of the variation in number of ears accounted for by the linear contribution of the phosphorus concentration (Figure 8).

The coefficient of variation (R^2) of phosphorus which was found to be significant ($P \leq 0.047$) was 11% for the treatment C_0, 1% for C_1 and 72% for C_2, indicating that 11, 1 and 72% of variation in phosphorus accounted for by the linear contribution of the treatment applied C_0, C_1 and C_2 respectively (Figure 9). The low variation in C_1 compared to the control treatment C_0 could be explained

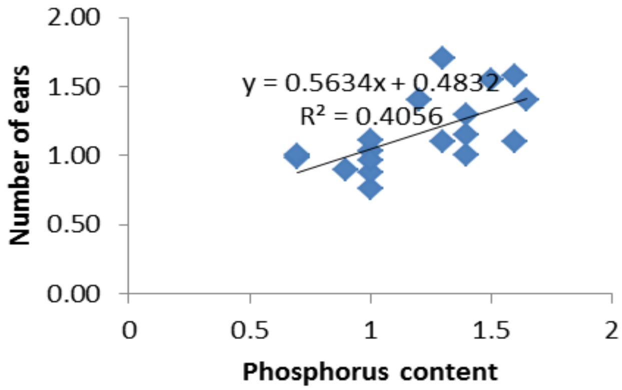

Figure 8. Trend line for regression between the number of ears and the soil phosphorus content**.**

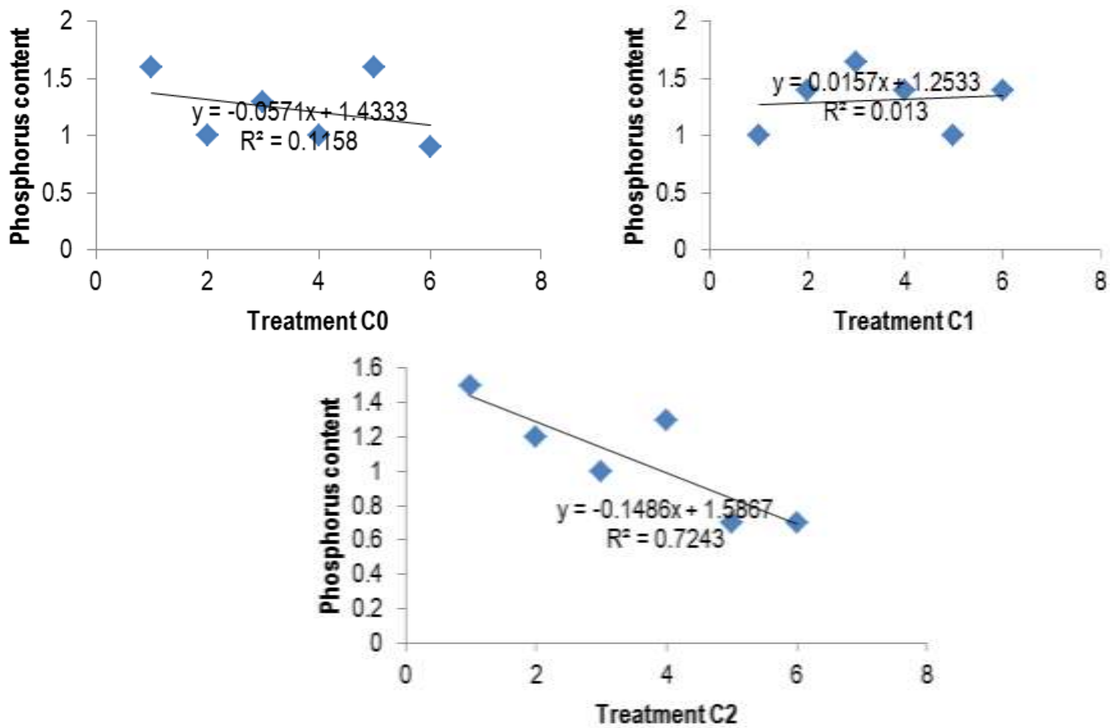

Figure 9. Trend line for regression between phosphorus content of soil and various levels of biochar treatment levels C_0, C_1 and C_2.

by the initial soil composition. Similar result was found by Nyami et al. (2016) who reported that biochar in combination with NKP fertilizer amendment improved the soil's phosphorus availability in Kinshasa DR Congo.

CONCLUSION AND RECOMMENDATION

This present study aimed at analyzing the use of charcoal (biochar) as soil amendment and its effects on performance on maize crop, focusing on the reduction rate of biogenic element loss through percolation in slash and burn agricultural production system in the forest region of Masako. The results of analysis of variance showed non-significant variation for most phenotypic traits and nutritional composition of soil after amendment, indicating in general that the treatments had the same effects on the soil composition for most of the parameters measured. Thus this study suggest that from pedological and agronomic perspective, there was not a clear impact of charcoal amendment as applied except on phosphorus content which was improved and collar diameter. It was observed that plots which received the amendment presented even a low soil fertility level than the control groups by the end of the experiment. Thus, these results should be integrated into the question related to the agricultural yield, in order to determine whether factors such as the nutrient balance due to the exportation through harvest, the spatial variability of soil nutrient content, the low level of amendment application which probably did not adequately modify soil chemical proprieties or the chemical nature (chemical contents) of the tree that the charcoal were derived from can be the leading rationale to be considered as major explanations to the relatively inconsistent results as shown by this experiment. Therefore, further studies could be conducted with higher levels of biochar rates including with a view of deducing the accurate contribution of charcoal amendment to soil nutrient content and try to answer several pending questions such as the effective charcoal doses able to trigger a long term effect as well as on maize and other commonly grown crop yield in the region of Masako. Moreover, it is recommended that the pyrolysis temperature, the type and physicochemical properties of feed stock as well as the initial composition of soil be determined prior to the experiment.

CONFLICT OF INTERESTS

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

ACKNOWLEDGEMENT

The authors would like to thank the soil laboratory of the Provincial Center of Land Analysis of Hulpe in Wallonia, Belgium.

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