

Green waste compost with wood ash additive improves physico-chemical and biological parameters of an Oxisol, and soybean (*Glycine max* L) yield

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Abstract— A greenhouse study was conducted to assess the potential of green waste wood ash compost on a tropical acid soil. Four types of compost (prepared with 0, 5, 10 and 15% of wood ash prior composting) were used to amend an Oxisol from the centre region of Cameroon. The different composts were mixed with the soil in 1/4 proportions (w/w); the experimental design was a completely randomized block with three replicates per treatment. The different treatments were planted with soybean (*Glycine max* L.) for three month growing period. Compost amendment increased the soil pH, organic carbon, total nitrogen and total phosphorus. Bacterial and fungal biomass together with cellulase and protease activities also increased in amended soil. Following soil chemical, physical and chemical parameters, plant growth and yield also improved in compost treated sols. However, compost prepared with 15% wood ash additive showed trends of inhibition of the soil microbiota. It can be concluded that green waste wood ash compost could be used as a suitable soil fertilizer for tropical acid soils, although precautions are to be taken when using these composts prepared with addition of wood ash $\geq 15\%$.

Keywords— Acid tropical soils, green waste, wood ash, compost, soybean.

I. INTRODUCTION

Acid tropical soils cover more than 500 million hectares (16.2%) of the African continent (Bationo *et al.*, 2006). These soils have poor fertility low pH, low organic matter composition, lack of essential elements necessary for plant growth such as N, K, P, Ca, Mg, and micronutrients. Additionally, they present Al and Mn toxicity (Kochian *et al.*, 2004). The intensive use of synthetic fertilizers, especially nitrogen (N) to achieve high yield often leads to soil degradation and acidification, which, in turn, deteriorates soil fertility and decreases crop yield (Ju *et al.*, 2009). Low-input agricultural system which relies on the input of organic materials hold great promise not only to minimize the use of synthetic fertilizer, but also to improve crop productivity and

to ensure ecosystem sustainability against nutrient mining and degradation of soil and water resources (Kravchenko *et al.*, 2017).

Composting is a microbiological biodegradation process during which biological waste is transformed into carbon dioxide, inorganic salts and humic substances, and the temperature generated is the result of metabolic activity of microorganisms (Bougnom *et al.*, 2018). The dissemination of composting is very welcome in developing countries like Cameroon since the country produces huge quantities of organic waste which are just discarded in the nature. Compost that has been produced with wood ash has a higher liming potential, and may thus reduce the amount of compost required to raise the pH to suitable levels for acid tropical

soils; moreover these composts improve several chemical and physical soil properties (Bougnom *et al.*, 2009). Composts have the potential to improve soil biological function (e.g., nutrient cycling) and suppress soil borne pathogens (Pane *et al.*, 2013; Suárez-Estrella *et al.*, 2013).

Wood ash is a by-product of the wood industry resulting from burning of wood

residues for energy production (Nkana *et al.*, 2002). Most of the inorganic nutrients and trace elements in wood are retained in the ash during combustion; the quality of the product depends on the quality of the wood, the tree species, and the burning process (Perkiömäki *et al.*, 2004). Wood ash is a considerable source of macro and micronutrients. Wood ash additive to compost could therefore allow to produce high value composts with stronger liming potential (Ohno, 1992). Wood ash compost has shown great potential in term of alleviating soil acidity and improving soil chemical, physical and biological parameters (Bougnom *et al.*, 2010).

This paper reports the potential of locally produced composts made from green waste and wood ash in term of alleviating soil acidity and improving soil fertility of a tropical acid soil.

II. MATERIAL AND METHODS

Soil sampling

The soil was collected from a low productivity field, located in the Centre region of Cameroon, in the locality of Nkolbisson (3° 51'N 11° 30'E). The soil is classified as an Oxisol (Nwaga *et al.*, 2010). Sampling was conducted over an area of 0.2 ha at a depth of 20 cm. Twenty-six samples were collected every 5 m on the four sides and diagonals of the fields, according to the sampling strategy (Figure 1). 20 kg of soil were collected.

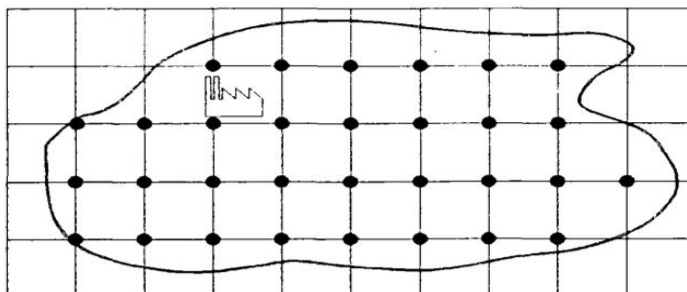


Fig. 1. Sampling area and sampling strategy

The different samples were mixed to obtain a composite sample. The samples were transported and stored in the greenhouse at room temperature before the experiments. The physical and chemical parameters of the soil are given in Table 1.

Table 1. Physical and chemical parameters of Nkolbisson soil

Parameters	
PH (water)	4.6
EC ($\mu\text{S.Cm}^{-1}$)	0.3
Corg (%)	1.3
Nt (%)	0.1

Pt (mg.kg^{-1})	1.1
C/N	11.5
Mg ²⁺ (mg.kg^{-1})	0.4
Ca ²⁺ (mg.kg^{-1})	0.7
K ⁺ (mg.kg^{-1})	0.06
Na ⁺ (mg.Kg^{-1})	0.03

Composts origin

The composts were produced in the greenhouse of the Department of microbiology of the University of Yaoundé I from green waste and wood ash (Bougnom *et al.*, 2018). Their physical and chemical parameters are given in Table 2.

Table 2. Physical and chemical parameters of the composts

Parameters	GWA 0%	GWA 5%	GWA 10%	GWA 15%
pH (water)	7.01	7.89	8.58	8.72
EC (mS.cm ⁻¹)	2.01	2.03	2.07	2.19
Corg (g.kg ⁻¹)	93.2	83.7	74.4	55.8
Ntotal (g.kg ⁻¹)	6.25	5.75	5.20	4.55
C/N	14.9	14.6	14.31	12.3
Pt (mg.Kg ⁻¹)	350	300	600	500
Pb (mg.kg ⁻¹)	0	0	0	0
Zn (mg.kg ⁻¹)	0.09	0.12	0.10	0.6
Cu (mg.kg ⁻¹)	1.04	2.69	2.07	1.62

GWA 0% : 100% green waste ; GWA 5% : 5% ash and 95% green waste ; GWA 10% : 10% ash and 9% green waste ; GWA 15% : 15% ash and 85% green waste

Plant material

Soybean (*Glycine max* L) variety TGx 1988-5F (NCRISOY-1) provided by the International Institute for Tropical Agriculture (IITA) was used as the growing plant during the experiment.

Experimental design

The experimental design was a randomized block with five treatments including the control, and the composts (GWA 0%, GWA 5%, GWA 10%, GWA 15%). The experiment was conducted in triplicate. The different composts were mixed with the soil in 1/4 proportions (w/w) for a total mass of 2 kg in each bucket. Three seeds were sown in each pot for a growing period of three months. The different treatments were as follows: T0 (Control); T1 (20% GWA 0% + 80% soil); T2 (20% GWA 5% + 80% soil); T3 (20% GWA 10% + 80% soil); and T4 (20% GWA 15% + 80% soil). The temperature in the greenhouse varied from 25-32 °C during the experiment.

Physical, chemical and biological analyses

After three months growing period, soil samples from each treatment were taken from each pot. One part was stored at 4 °C for biological analyses, the other part was air-dried and sieved to 2 mm for physical and chemical analyses. The different analyses were carried out for each repetition. pH and EC (electrical conductivity) were measured in a 1: 2.5 (soil: demineralized water) ratio using a glass electrode. Organic C (Corg), and total N that were determined by dry combustion at 950 °C in a C, N, H analyzer. Nutrients (P, K, Ca, Mg, and Na) and heavy metal (Pb, Cu, and Zn) were determined after wet digestion by inductively coupled plasma atomic emission

spectroscopy (ICP-AES). Total aerobic mesophilic bacteria (total bacteria), and total fungi in soils were isolated and enumerated on Luria broth agar (LB) and Potato dextrose agar (PDA), respectively, and results expressed as colony forming units (CFU) per gram dry soil. The activity levels of compost enzymes cellulose and protease were also measured as described by Tabatabai (1994). Growth parameters (height, stem length, leaf area, number of leaves) and yield were also evaluated.

Statistical analyses

The data obtained were statistically analysed using the statistical software SPSS 20 for Windows. The data obtained were subjected to a two-way analysis of variance (ANOVA) followed by a Tukey's B-test at 5% level.

III. RESULTS AND DISCUSSION

Following compost amendment, soil pH, electrical conductivity (EC), organic carbon (Corg), total nitrogen (Nt), and total phosphorus (Pt) of the treated soil significantly increased. The C/N ratio ranged from 16.6 to 18.5 (Table 3). The increase in soil pH was proportional to the amount of wood ash in the composts. The highest value was obtained under T4 amendment (7.42) although it was not significantly different with those obtained under T3 (7.32) and T2 (7.25). EC increased after compost amendment, ranging from 1.31 μS. cm⁻¹ to 0.97 μS.cm⁻¹ among the treated soils. Both organic carbon and total nitrogen increased under compost amendment. The greater values were obtained under T2 (organic carbon (3.2%) and total nitrogen (0.19%)).

However, these values were not significantly different from those of T1 and T3. Following organic carbon increased, total phosphorus also increased significantly in the amended soils

treatments. The greatest value was obtained under T1, T2, T3 amendment (16.7 mg.kg⁻¹).

Table 3. pH, EC, organic carbon, total nitrogen, C/N ratio and total phosphorus in the different treatments (mean±SD).

Parameters	Treatments				
	T0	T1	T2	T3	T4
pH (water)	4.5±0.20a	6.82 ±0.09b	7.25 ±0.16cb	7.32 ±0.2cb	7.42±0.3c
CE (µS/Cm)	0.04±0.02a	1.31 ±0.23b	1.23 ±0.21b	1.20 ±0.16b	0.97±0.1b
C _{org} (%)	1.50± 0.05a	3 ±0.36cb	3.2 ±0.2c	2.8 ±0.36abc	2.04± 0.4ab
N _{total} (%)	0.1± 0.01a	0.18 ±0.01c	0.19 ±0.01c	0.16 ± 0.02cb	0.13± 0.00ba
C/N	18.7±0.50a	16.6 ±5.52a	16.8 ±5.14a	17.5 ±2.35a	18.5 ±2.32a
P _t (mg.kg)	2 ± 1.10a	11.1 ±0.7c	11.7 ± 0.5c	16.7 ±0.8d	8.30 ± 0.20b

Dissimilar letters in a column indicate statistically significant differences among the different treatments (n=3; Tukey B-test).

One of the multifunctionality of the soil is its ability to ensure good growth for cultivated plants, which provides information on its ability to supply the plant with nutrients and therefore determines its level of fertility (Bünemann *et al.*, 2018). As the initial pH of the soil is low (4.6), the addition of high pH composts (7.01-8.72) has increased the hydroxide content of the soil, thereby increasing the pH. According to Mkhabela and Warman (2005), the presence of hydroxyl groups and certain ions in waste composts is the main factor which contributes to the rise of the pH in the soil. These results are in accordance with previous studies which have shown the

ability of composts to alleviate soil acidity by improving soil pH (Houot *et al.*, 2009; Mulaji, 2011). Indeed, wood ash additive to the composts increased their proton consumption capacity, that is why higher pH was observed under T4 (Bougnom *et al.*, 2010).

Significant increase in salt content were observed in the amended soils at the harvest (Table 4). Concentration of Ca²⁺ and Mg²⁺ were higher under T3 and T4 while those of K⁺ and Na⁺ were higher under T1 and T2 among the amended soils.

Table 4. Concentration of exchangeable Ca²⁺, Mg²⁺, K⁺ in the different treatments (mean±SD).

Parameters	Treatments				
	T0	T1	T2	T3	T4
Ca ²⁺ (mg.kg ⁻¹)	0.8 ± 0.1 ^a	1.66 ± 0.7 ^b	1.75 ± 0.17 ^b	2 ± 0.13 ^c	2 ± 0.2 ^c
Mg ²⁺ (mg.kg ⁻¹)	0.3 ± 0.01 ^a	0.55 ± 0.15 ^a	0.87 ± 0.01 ^b	1 ± 0.02 ^c	1.13 ± 0.07 ^c
K ⁺ (mg./kg ⁻¹)	0.05 ± 0.01 ^a	0.32 ± 0.05 ^c	0.3 ± 0.04 ^c	0.16 ± 0.05 ^b	0.08 ± 0.00 ^a
Na ⁺ (mg.kg ⁻¹)	0.03 ± 0.01 ^a	0.6 ± 0.03 ^c	0.55 ± 0.01 ^{cb}	0.5 ± 0.04 ^b	0.5 ± 0.03 ^b

Dissimilar letters in a column indicate statistically significant differences among the different treatments (n=3; Tukey B-test).

The compost had higher content in exchangeable cations (Ca²⁺, Mg²⁺, K⁺, Na⁺); the increase in salt content was thus expected. Buffering capacity in soil is mainly conducted by Ca²⁺. Soil acidity occurs when Al has undertaken buffering capacity and thus lead to Al toxicity. Moreover, to avoid nutrients leaching, tropical soils should have good content in soil organic matter (SOM) which is provided by the composts.

Compost fertilization increases soil organic matter and soil quality (Meena *et al.*, 2019). The increase in the concentration of exchangeable cations coupled with SOM is positive for the plant which will find necessary minerals and favourable conditions for water retention for its growth. Electrical conductivity (EC) is linked to salts concentration. An increase in exchangeable cations (Ca²⁺, Mg²⁺, K⁺, Na⁺) automatically

led to an increase in electrical conductivity in amended soils. However, EC was in the range acceptable for agricultural fields ($<2 \text{ mS.cm}^{-1}$) (Kuba *et al.*, 2008). Thus, our compost did not lead to a dramatically increase of salt content. For an optimal nitrogen availability to plants, a C/N ratio ranging from 12-20 is recommended (Hue and Sobiesczyk, 1999). C/N ratio <12 would imply the risk of nitrogen leaching, while a C/N > 20 ratio could cause nitrogen immobilization (Insam and Merschak, 1997). The C/N ratios of the amended soils ranged from 16-18; thus, the composts do not present a risk of nitrogen immobilization or nitrate leaching. Overall, our results are in accordance with those of (Eldridge *et al.*, (2014) who have reported that application of compost results in improvements of many key soil chemical properties generally associated with soil quality including cation exchange

Table 5. Total bacteria, total fungi, cellulase and protease activities in the different treatments (mean \pm SD).

Parameters	Treatments				
	T0	T1	T2	T3	T4
Total bacteria (Log CFU.g ⁻¹)	0.85 \pm 0.01 ^a	3.29 \pm 0.17 ^d	3.05 \pm 0.41 ^b	2.9 \pm 0.21 ^b	2.42 \pm 0.04 ^c
Total fungi (Log CFU.g ⁻¹)	0.47 \pm 0.03 ^a	0.83 \pm 0.05 ^c	2.05 \pm 0.12 ^{ab}	1.9 \pm 0.18 ^c	0.52 \pm 0.04 ^b
Cellulase activity (U.g ⁻¹ .h ⁻¹)	0.5 \pm 0.04 ^a	1.11 \pm 0.15 ^b	1.10 \pm 0.2 ^b	1.09 \pm 0.1 ^b	1.09 \pm 0.09 ^b
Protease activity (U.mg-1.2h-1)	0.23 \pm 0.01 ^a	0.54 \pm 0.01 ^b	0.53 \pm 0.04 ^b	0.51 \pm 0.09 ^b	0.50 \pm 0.01 ^b

Dissimilar letters in a column indicate statistically significant differences among the different treatments (n=3; Tukey B-test).

Basic soil biological properties were assessed to evaluate the effect of the produced composts on soil microbial communities. Previous studies have reported changes in bacterial and fungal communities after application of compost and /or wood ash, with the fungal community being more sensitive to the dose of ash (Baath *et al.*, 1995). The increase in bacterial and fungal biomass could be due to an improvement in the growing conditions for native microorganisms after compost amendment, in addition to the bacterial and fungal populations provided by the composts. The incorporation of easily degradable materials and exogenous microorganisms contained in organic waste is known to stimulate the indigenous microbial activity of the soil and that will lead to the shift of microbial communities (Ros *et al.*, 2006). Compost addition increases availability of nutrients in soils, stimulate microbial growth and thus microbial biomass (Gracia *et al.*, 2000). An increase in soil pH affects microbial biomass and microbial activity and induces the development of bacteria to the detriment of fungi (Perucci *et al.*, 2006). The decline in microbial growth observed in T3 and T4 treatments indicates caution when using large amounts of wood ash in compost for agriculture. Wood ash contains heavy metals, which in high

capacity (CEC) important for nutrient storage, total organic C, plant available potassium, exchangeable calcium, plant available phosphorus, and pH beneficial to the crops.

Compost fertilization had a positive impact on the soil microbial biomass. A significant increase in bacterial and fungal biomass was observed in all treated soils, compared to the control (Table 5). The most important bacterial growth was observed under T1 ($3.29.10^5$), while most important fungal growth was observed under T2 ($2.05.10^5$). Consequent to Bacterial and fungal growth, cellulase and protease activities significantly increased in the amended soils (Table 5). Both cellulase and protease activities did not differ among the treated soils.

concentrations inhibit microbial activity (Gupta *et al.*, 2002). Soil microbial enzymes are mainly driven by metabolic processes, largely reflecting the level of soil microbial activity and the intensity of biochemical reactions. Indeed, Soil enzyme activities have been suggested as sensitive indicators of soil fertility since they catalyze the principal biochemical reactions (i.e., nutrient cycling, degradation of organic nutrient, and xenobiotics) that are essential for the maintenance of soil fertility (Nannipieri *et al.*, 2012; Burns *et al.*, 2013). The increased activities of cellulase and protease in amended soil compared to the control (Table 6) suggested that compost amendment would be a vital strategy to improve soil C and N turnover and fertility. The increase in enzymatic activities in amended soils is a consequence of the increase in microbial biomass. Soil enzymes respond quickly to any change in soil management and are potential indicators of soil quality because they are closely linked to the activity and abundance of microorganisms (Caldwell, 2005). Cellulase activity is mainly the action of fungi, while protease activity is that of fungi and bacteria (Rhee *et al.*, 1987). The increase of these enzymes in amended soils indicates soil health improvement, and therefore the eco-compatibility of our composts.

The leaf area (SF), length of the stem (TA), number of leaves (NF) of soybean after cultivation are reported in Table 6. These parameters significantly increased in compost

amended soils, compared to the control. However, the differences were not significant in the amended soils.

Table 6. Stem size, leaf surface and the number of leaves of the growing plant in the different treatments (mean±SD).

Parameters	Treatments				
	T0	T1	T2	T3	T4
Stem size (cm ²)	32.5±2.24a	47.8±3.75b	49.3±4b	50.1±3.9b	54.3±4.2b
Leaf surface (cm)	26.3±2.3a	45±3.42b	49±3.5b	51±4b	51±4.3b
Number of leaves	15.8±1.8a	41±3b	47±4.2b	49±4b	51±4.5b

Dissimilar letters in a column indicate statistically significant differences among the different treatments (n=3; Tukey B-test).

Soybean yield (average seed mass) after harvesting is reported in Figure 2. Compost amendment had a clear impact on soybean yield which significantly improved in compost amended soils. Best yield was obtained under T4. No significant difference was observed under T2 and T3.

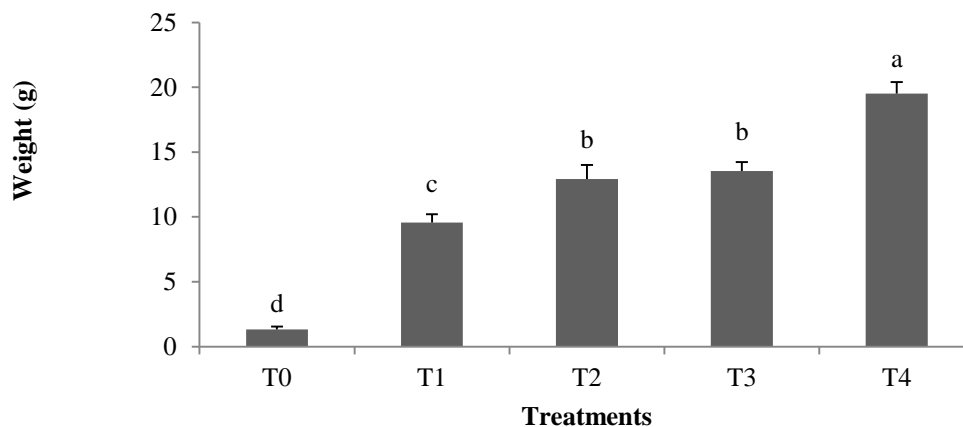


Fig. 2. Average seed mass of soybean in the different treatments after three months growing period. Dissimilar letters indicate statistically significant differences among the different treatments (n=3; Tukey B-test).

The increase of growth parameters and yield of the growing soybean following soil amendment could be attributed to the improvement of physical, chemical and biological properties of the amended soils which created favourable conditions for the plant growth. Plants growing in amended soils with compost are stronger and have better yield (Duplessis, 2002). For example, addition of composts had positive effects on the yield of tomatoes, plant biomass, number of fruits and roots weight (El Hanafi Sebti, 2006).

The main objective of this work was to test the potential of locally produced green waste wood ash composts for improving soil fertility of a tropical acid soil. Our results showed that green waste wood ash compost amendment improves soil physical chemical and microbial parameters of an Oxisol. Following soil parameters improvement, the composts significantly stimulated bacterial and fungal growth, together with cellulase and protease activities. The different positive changes led to an improvement of plant health and yield. However, composts enriched with higher quantity of wood ash ($\geq 15\%$) showed impairment on soil microbial biota. Thus, the use of wood ash enriched composts in tropical agriculture should be done with cautious; composts with concentration of wood ash over 15% should be used with

IV. CONCLUSION

caution. Future studies involving a long-term field study are necessary to assess the sustainability of our composts for tropical acid soils.

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