INNSPUB

International Journal of Agronomy and Agricultural Research (IJAAR)

ISSN: 2223-7054 (Print) 2225-3610 (Online)

http://www.innspub.net

Vol. 13, No. 5, p. 35-45, 2018

RESEARCH PAPER

OPEN ACCESS

Evaluation of wood ash as additive for green waste composting

Blaise P. Bougnom*[1], Alain M. Sontsa-Donhoung[1], Dieudonne Onguene[1], Pauline Mounjouenpou[2], François X. Etoa[1]

[1]*Department of Microbiology, Faculty of Science, University of Yaoundé I, Yaounde, Cameroon*

[2]*Agricultural Research Institute for Development (IRAD), Yaounde, Cameroon*

Article published on November 16, 2018

Key words: Compost, Wood ash, Green waste, Tropical agriculture.

Abstract

A study was conducted to produce composts with a high liming potential using both green waste and wood ash for use in agriculture. increased proportions of wood ash were co-composted with green waste. During composting, all the produced composts presented the classical composting temperature curve and reached a thermophilic composting phase (P ≥50 °C) which lasted for 8 days. The produced composts had a C/N ratio between 10 and 15, and their pH was above neutrality, meaning maturity. They were rich in nutrients (Mg, K and Na) and poor in heavy metals (Pb, Zn, and Cu). Wood ash addition did not impair neither the bacterial nor the fungal communities; however, addition of high amounts of wood ash could reduce the metabolism of the microbial communities including cellulase activity that showed a proportional decrease according to the added amount. The composts showed a germination index greater than 100% at all concentrations. It could be concluded that co-composting green waste with wood as hallowed to obtain a good organic fertiliser with higher liming potential, nutrient content, and less hazardous material which could beused to remediate soil acidity of tropical soils.

* **Corresponding Author:** Blaise P. Bougnom ✉ bpbougnom@uy1.uninet.cm

Introduction

Composting is a microbiological biodegradation process during which bio-waste is transformed into carbon dioxide, inorganic salts and humic substances, and heat is generated resulting from the metabolic activity of microorganisms. During maturation, organic matter is stabilised and complex polymerisation reactions take place, producing humic-acid like substances. The use of compost in agriculture aids in replenishing and maintaining long term soil fertility by enhancing soil biological activity and providing nutrients that are slowly released in accordance with the crop needs (Gobat *et al*., 2003; Ros *et al*., 2006); addition of compost to a soil modifies considerably its biological, physical and chemical proprieties in short and long term (Ryckeboer, 2003). Compost could also be an amendment for soils lacking organic matter like tropical soils. If the habit of composting is well introduced in developed countries where compost plant units are found in many places, it is poorly implemented in the tropics. In developed countries, in many cities, green waste is generally collected separately from other wastes and then composted, either alone or with other organic wastes and used in products such as garden mulch, organic soil amendment, garden compost, and soilless-potting media or "manufactured soil" (Belyaeva and Haynes, 2009). Compost made from green wastes is of high quality with low salt content, low levels of contamination with regard to both potentially toxic elements (heavy metals) and inert fragments such as glass, metal and plastic (Brinton, 2000). In the tropical humid zones where soil acidity occurs, big quantities of green waste are generally generated following clearing and weeding of farms, tracks, paths, leisure spaces and around houses. In those areas, green waste is the far most available organic waste comparing to household wastes, and thus all year long available, with the highest amounts obtained during the rainy seasons. The recycling of this waste within the farming system could allow to increase the level of carbon sequestration and allow the soil system to maintain a higher level of C, thus enhancing soil quality and long-term agronomic productivity as well as greenhouse gas emissions and global warming (Brown *et al.,* 2008).

In many African regions, fuel-wood constitutes 61 to 86% of primary energy consumption and generates big quantities of wood ash, causing serious environmental problems (Samir Amous, 1999; Bougnom *et al*., 2011). Wood ash is a by-product of the wood industry resulting from burning of wood residues for either energy production or waste reduction (Nkana *et al.,* 2002). Most of the inorganic nutrients and trace elements in wood are retained in the ash during combustion (Perkiömäki *et al.,*2004). Wood ash is a significant source of P, K, Mg, Ca and lime, and could well be used as a supplement to fertilisers (Ohno, 1992; Bougnom and Insam, 2009). Agriculture and forestry remove plant nutrients from the soil, and these nutrients have to be replaced. Ash fertilisation can compensate for the nutrient losses caused by harvesting, nutrient leaching and soil acidification (Saarsalmi *et al.,* 2006). Wood ash has similar properties as lime with the advantage of additionally carrying micronutrients and has been used to alleviate nutrient deficiencies and acidification (Nkana *et al.,* 2002; Maljanen *et al.,* 2006; Insam *et al*., 2009). However, wood ash also can contain surprisingly high levels of heavy metals such as lead, zinc and cadmium. But, if only the so-called bottom ash is used, wood ash addition to organic wastes prior to composting is known to improve compost quality and could serve particularly well the purpose of ameliorating acid tropical soils (Kuba *et al.,* 2008; Bougnom *et al.,* 2009; 2010).

Co-composting green wastes with wood ash as an additive could result in a nutrient rich compost with higher liming potential and less potentially toxic elements (heavy metals).

It is cost effective, efficient, environmentally safe, economically viable and ecologically sound. That is of relevance in relation to the management of soil fertility by resource-poor, subsistence farmers in the tropics where acid soil infertility is often a major limitation to crop production, whilst lime, fertiliser P and N, as well as other chemical fertilisers and agrochemicals are expensive.

The purpose of this study is to use both green waste and wood ash to produce good compost. The idea is to use proportional amounts of green wastes and wood ash to produce a good organic fertiliser, by optimizing the proportion of the ash to be mixed up with green waste in order to get best quality compost with higher liming potential, nutrient content, and less hazardous material.

Materials and methods

Properties of input materials

For comparative purposes, four (4) types of compost in proportion of 0, 5, 10 and 15% wood ash/ green wastes (w/w) were produced, labelled GWA 0%, GWA 5%, GWA 10% and GWA 15% respectively. Green wastes consisted of tree branches, shrubs garden hedges, plants, leaves and grass cutting that was mechanically shredded; wood ash (bottom ash) was collected at a wood incineration plant in Yaounde, Cameroon. Physical and chemical analysis of the input materials (wood ash and green wastes) are reported in Table 1.

Online monitoring of the composting

Composting was carried out in composting bins of 10litres for 4 months. The experiment was a randomized block design with three replicates. Temperature and CO_2 evolution was measured weekly for the whole composting period (Kuba *et al.,*2008). The bins were wrapped with plastic tilt to prevent excessive heat loss during composting. Additional holes were cut around the bins to provide improved aeration and piles were turned once a month in order to ensure adequate O_2 levels inside piles. Temperature was monitored at a depth of 15 cm inside the piles at 10:00 h twice a week. The water content of piles was maintained at 60% of their water holding capacity throughout the 4-months experiment and water was added once a month, if necessary, after piles were turned. At the end of the composting process, measurements of the different physical, chemical and biological parameters of the produced composts was carried out. Moisture content was determined by weight loss at 105°C (Wong *et al.,* 1998). Three subsamples were taken randomly from within each pile, they were bulked and homogenised. Part of each sample was stored at 4 °C for biological analysis and the rest was air-dried and stored for physical and chemical analysis.

Physical,chemical and biological analysis

pH and EC(electrical conductivity) were measured in a 1:2.5 (soil: demineralized water) ratio using a glass electrode. Organic C (C_{org}), and total N that were determined by dry combustion at 950°C in a C, N, H analyser. Nutrients (P, K, Ca, Mg, and Na) and heavy metal (Pb, Cu, and Zn) contents that were determined after wet digestion by inductively coupled plasma atomic emission spectroscopy (ICP-AES).The biological tests consisted in the determination of the total aerobic cultured mesophilic bacteria (total bacteria), viable and total fungi in composts that were isolated and enumerated on Luria broth agar and Potato dextrose agar (PDA) respectively, and results expressed as colony forming units (CFU) per gram dry compost. The activity levels of compost enzymes cellulaseand protease were also measured as described by Tabatabai (1994).

Phytotoxicity test

To evaluate the compost maturity and their phytotoxicity, a germination assay was conducted with corn seeds and the Germination Index (GI) was determined according to Zucconi *et al.,* (1985). The germination test was carried out (in triplicate) on filter paper in petri dishes. Ten corn seeds were placed onto filter paper, two millilitres of aqueous extract (1/10 W/V) from composts was added to dishes and the dishes were placed in the dark at 25 °C. Petri dishes with corn seeds and sterile distilled water was the control.

The germination percentages with respect to control and root lengths were determined after 6 days. The GI was calculated as $GI = \%G \times Le/Lc$, where %G is the percentage of germinated seeds in each extract with respect to control, Le is the mean total root length of the germinated seeds in each extract and Lc is the mean root length of the control. The control GI value is considered as 100%.

Statistical analyses

The data obtained were subjected to a two-way analysis of variance (ANOVA) followed by a Tukey's B-test at 5% level. The data were analysed using SPSS Software Package 16.

Results

Material characteristics

The physical, chemical properties and the micronutrients content of the green waste and wood ash are reported in Table 1. pH and EC were higher in wood ash; C and N were higher in green waste. Concentrations were: Zn, 0.09 and 0.28; Cu, 2.89 and2.12 mg/kg for green waste and wood ash, respectively.

Table 1. Physical and chemical properties of the green waste and wood ash used.

Parameters	Green waste	Wood ash
pH (water)	7.03	9.68
EC ($mScm^{-1}$)	1.42	4.87
C (gkg^{-1})	130.23	74.41
N_{total}(gkg^{-1})	6.3	1.9
P ($g.kg^{-1}$)	5	6
Mg^{2+} ($g.kg^{-1}$)	2.2	2.1
Ca^{2+} ($g.kg^{-1}$)	20.3	28.5
K^+ ($g.kg^{-1}$)	8.1	1.5
Na^+ ($g.kg^{-1}$)	1.5	2.44
Pb ($mg.kg^{-1}$)	0.68	24.5
Zn ($mg.kg^{-1}$)	0.09	0.28
Cu ($mg.kg^{-1}$)	2.89	2.12

Composting temperature

The variations of temperature during composting are shown in Fig. 1. The temperature dynamic was similar in all the composting bins. At the beginning of the process, the temperature of the composting bins was the ambient temperature, and then the temperature increased. The heating period was between day 24 and day 59. After that, all the compost bins reached the ambient temperature. The temperature peak was about 55°C for about 6 days, and that meet the legal hygiene requirement of a minimum of 6 days.

Table 2. pH, EC, C, N,C/N, and P of the produced composts made with increasing percentages of added wood ash.

Treatment	pH (Water)	EC ($mS.cm^{-1}$)	P($mg.kg^{-1}$)	C ($g.kg^{-1}$)	N($g.kg^{-1}$)	C/N
GWA 0%	7.01 ± 0.12^a	2.01 ± 0.77^a	350 ± 70.71^a	93.2 ± 9.9^a	6.25 ± 1.90^a	14.9^a
GWA 5%	7.89 ± 0.16^{ab}	2.03 ± 0.22^a	300 ± 77.7^a	83.7 ± 39.4^a	5.75 ± 1.34^a	14.5^a
GWA 10%	8.58 ± 0.04^b	2.07 ± 0.48^a	600 ± 282.8^a	74.4 ± 26.3^a	5.20 ± 0.98^a	14.3^a
GWA 15%	8.72 ± 0.22^b	2.19 ± 0.57^a	500 ± 35.3^a	55.8 ± 15.7^a	4.55 ± 0.91^a	12.2^a

Means followed by the same letter in a column are not significantly different at $P \leq 0.05$.

Physical and chemical properties

The physical and chemical properties and the micronutrients content of the produced composts are reported in Table 2 and 3. At the end of the composting, the pH of GWA 0%, GWA 5%, GWA 10%, GWA 15%was 7.01; 7.89; 8.58; and 8.72, respectively. Wood ash additive significantly increased the pH in GWA 10% and GWA 15%. EC did not significantly change among the different composts. Wood ash addition did not have an impact on concentrations of C, N, and the C/N ratio. Concentration of N and C was lower in composts with wood ash, but the difference was not significant (Table 2). Concentration of exchangeable cations Mg and Ca, fluctuated among the different composts, with no significant difference; while those of K and Na increased in the amended composts. Regarding heavy metals, concentration of Pb increased in amended composts, those of Zn and Cu did not significantly change (Table 2).

Table 3. Extractable nutrients and heavy metal content of the produced composts made with increasing percentages of added wood ash.

Treatment	Exchangeable cations (mg.kg-1)				Heavy metal (mg.kg-1)		
	Mg	Ca	K	Na	Pb	Zn	Cu
GWA 0%	75 ± 49.4^{a}	240 ± 56.5^{a}	0.09 ± 0.03^{a}	850 ±178^{a}	0.9 ± 0.1^{a}	0.09 ± 0.03^{a}	1.04 ± 0.27^{a}
GWA 5%	80 ± 56.5^{a}	220 ± 28.3^{a}	60 ± 1.41^{b}	1500 ± 229.1^{b}	28.4 ± 2.5^{b}	0.12 ± 0.02^{a}	2.69 ± 0.35^{a}
GWA 10%	90 ± 42.4^{a}	240 ± 12.0^{a}	66 ±1.41^{b}	1923 ± 245.9^{b}	30.1 ± 3.6^{b}	0.10 ± 0.07^{a}	2.07 ± 0.46^{a}
GWA 15%	205 ± 35.3^{a}	200 ± 28.3^{a}	82 ± 2.82^{b}	2112 ± 379.2^{b}	35.1 ± 4.9^{b}	0.6 ± 0.02^{a}	1.62 ± 0.31^{a}

Means followed by the same letter in a column are not significantly different at $P \leq 0.05$.

Biological properties

Wood ash addition had a positive impact on both bacterial and fungal population. The fungal biomass was higher in GWA 15%; and the bacterial biomass was higher in GWA 10% and GWA 15%, respectively (Table 4). Wood ash addition did not impair both cellulase and protease activities since the difference were not significant between amended and not amended compost. Cellulase activity was greater than protease activity for the different composts; in addition, cellulase activity seems to be inhibited by increasing wood ash addition (Table 5).

Table 4. Microbial biomass counted in compost samples.

Treatment	Microbial biomass (.10^{5} UFC.g^{-1} compost)	
	Bacteria	Fungi
GWA 0%	46.2±1.49^{a}	26.6±6.27^{a}
GWA 5%	48.1±6.41^{a}	28.4±0.15^{a}
GWA 10%	86.2±0.75^{b}	29.9± 5.50^{a}
GWA 15%	90.3±7.42^{b}	56.9±1.04^{b}

Means followed by the same letter in a column are not significantly different at $P \leq 0.05$.

Germination index

Wood ash addition was not toxic to the seeds and seedlings at the concentration of 10% and 30%. However, extracts of GWA 0%, GWA 10% and GWA 15% at concentration of 50 % had a negative impact on the seeds and seedlings (Fig.2).

Discussion

Composting process

The temperature dynamics observed with sequential mesophilic, thermophilic and cooling phases in the different composting piles is typical for composting processes (Insam and de Bertoldi, 2007). Leclerc (2001) reported that suitable temperature to start composting should vary from 20 to 45°C, which was the case.

The temperature increase from day 28 in the different compost piles was the result of an intense microbial activity following degradation of simple molecules present in the substrate by microorganisms (Barje *et al.*, 2012; El Fels *et al.*, 2014).

With temperature of 55°C for about 6 days, the four composts have met the legal requirements concerning compost hygiene (Albrecht, 2007).

Table 5. Enzyme activities in green waste-based composts made with increasing percentages of added wood ash.

Treatment	(U/mg compost.h^{-1})	
	Cellulase activity	Protease activity
GWA 0%	1.91±0.39[a]	0,23±0.03[a]
GWA 5%	1.71±0.19[a]	0.21±0.01[a]
GWA 10%	1.68±0.14[a]	0.29± 0.12[a]
GWA 15%	1.37±0.27[a]	0.45±0.29[a]

Means followed by the same letter in a column are not significantly different at P ≤ 0.05.

The temperature decrease was due to the depletion of the medium in readily metabolizable organic compounds (Amir, 2005); and its stabilisation around 24°C at the end of the process indicates that the compost has achieved a state of considerable maturity with no more substrate to degrade. Wood ash pH was higher than the one of green waste; it was therefore not a surprise to observe an increased pH in wood ash composts. Wood ash is rich in carbonates, oxides and hydroxides of its Mg, Ca and K responsible of strong basicity; thus, explaining the differences observed between the composts (Vance, 1996).

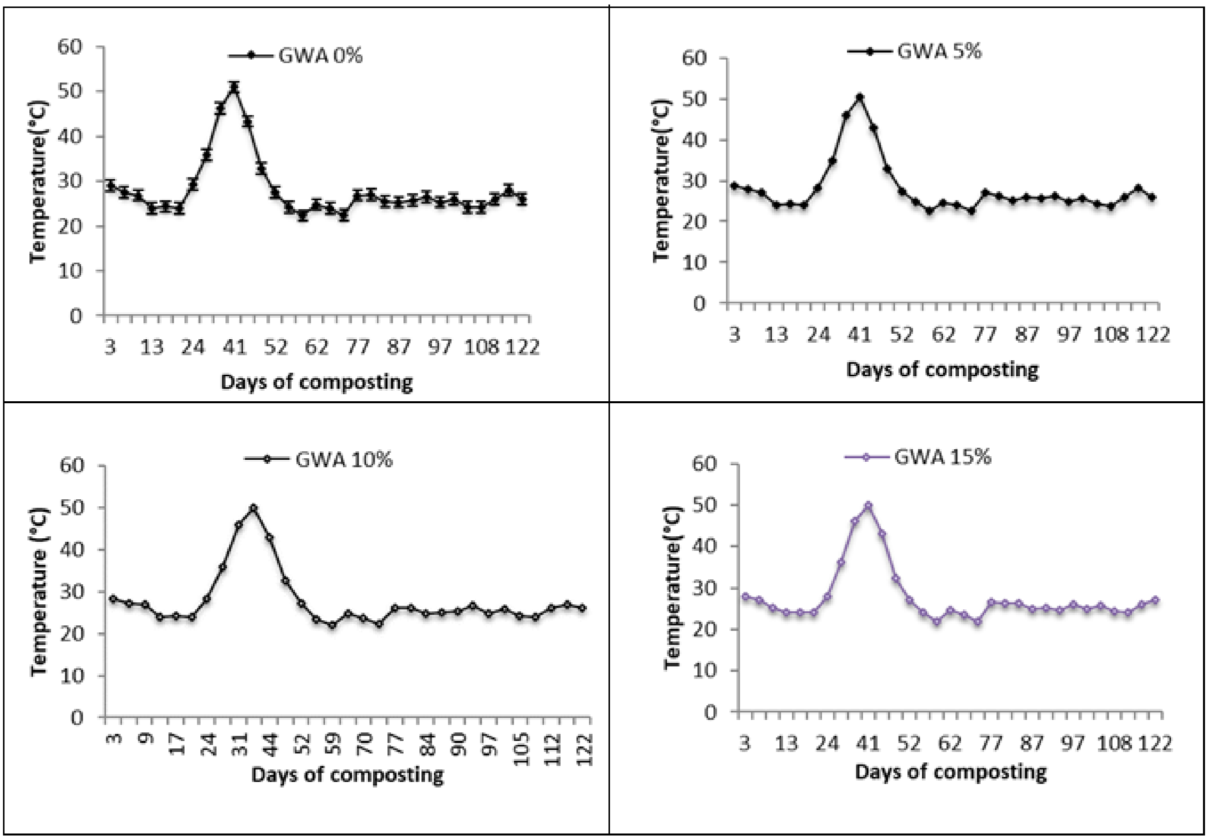

Fig. 1. Temperature during composting of green waste-based composts made with increasing percentages of added wood ash. GWA 0%=100% green waste, GWA 5%= 95% green waste/5% wood ash, GWA 10%=90% green waste/10% wood ash,GWA 15%=85% green waste/15% wood ash.

A mature compost must have a pH value between 7 and 9 (Francou, 2003), the produced composts have met this criterion. A higher pH confers a higher buffering capacity, that is a good attribute for the wood ash composts. The electrical conductivity measures the salinity; compost EC is highly dependent to its nutrient content and should be between 2-3 mS.cm^{-1} for use in agriculture, a higher

EC means toxicity for the plants (Saebo and Ferrini, 2006). Wood ash addition did not negatively impact on the compost since their EC oscillated between 2.01 and 2.19 $mS.cm^{-1}$.Although the difference was not significant, C and N in GWA 0% was greater than the wood ash composts.

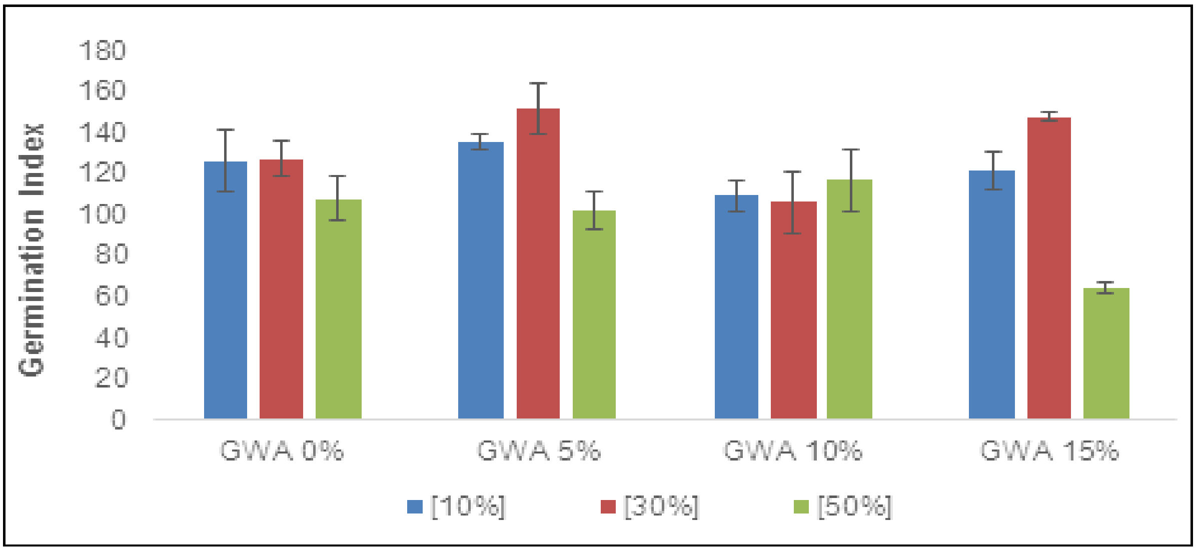

Fig. 2. Germination index in green waste-based composts made with increasing percentages of added wood ash.Means followed by the same letter are not significantly different at P ≤ 0.05.

The decrease in content can be explained by the continuous mineralisation of organic compounds resulting in the depletion of the medium into easily degradable compounds, as well as the dominance of the precursors of humic substances (Mustin, 1987; Francou, 2003), while decrease of nitrogen content is mainly related to losses of nitrogen in the form of volatile ammonia (NH_3) or nitrate oxyde (N_2O) (Francou, 2003; Albrecht, 2007). NH_3 losses is closely correlated to the pH and would occur during the intensive degradation phase where under optimal aeration conditions, the rise in pH would lead to the conversion of NH_4^+ to volatile NH_3.Wood ash having higher pH, carbon and nitrogen losses was greater in wood ash compost piles. Compost is considered mature when it has a C/N ratio between 10 and 15 (Barje *et al.*, 2012), and all the produced composts in this study met this criterion. Micronutrients concentration of Zn and Cu in composts give information on their eco-compatibility, an excessive concentration of these elements in composts indicate their chemical degradation and threat to the environment; concentration in macronutrients, such as K, Ca, Na, and Mg which are indicators of the fertilizing capacity of composts (Akram, 2002).

The increase in micronutrients and macronutrients in wood ash composts could be explained by the ash additive, after wood combustion, these nutrients are retained in the ash. Considering that the heavy metal contents of wood ash exceeded those of the green waste, this might decrease the quality of the amended compost. All except Pb, the heavy metals content of the composts was not significantly different, this could be explained by the low heavy metal contents in the wood ash.

Microbial parameters

The values of bacterial and fungal biomass showed that wood ash admixture did not had a negative impact on the bacterial and fungal communities. They were even a stimulation of the bacterial in GWA 10% and both bacterial and fungal communities in GWA 15% which might be consequent to the improvement of growth conditions following ash addition. Enzymatic activities of composts are considered sensitive to sources the quality of materials. Thus, enzymatic activities are considered to effective indicators of abiotic stresses mainly due to the presence of heavy metals. Relationship between individual biochemical properties and total microbial activity is not always evident, especially in complex systems such as compost where microorganisms and processes involved in the degradation of organic compounds are highly various (Belyaeva and Haynes, 2009). Bhattacharya and Pletschke (2014) reported that the increase in cellulase activity in normal compost corresponds to an increase in the biomass of thermophilic *Bacilli* towards the end of the composting period. Although the difference was not significant, we noticed a decrease in cellulase activity in wood ash compost proportionally to the amount of ash added. Overall, the protease activity was relatively weak; this could be explained by the relative low protein content of the composts following an intense proteolytic activity by microorganisms during composting. Although not significant, protease activity decreased with wood ash addition with GWA15% having the lowest activity.

Therefore, addition of wood ash could not affect the number of microorganisms but hada negative effect on their metabolism if the added amount is important. Consequently, their careful use in agriculture is recommended.

Phytotoxicity evaluation

Immature compost may contain phytotoxic compounds (Zucconi *et al.*, 1983). The concentration of extract, high ionic charge of the water-soluble extracts and EC could cause a possible osmotic effect, along with excessive of micronutrients which can induced an inhibitory effect on the germination and growth of plants (Marcato-Romain *et al.*, 2009).

In our case, the amount of wood ash added did not affect seed germination, GI values which were even greater in GWA 5%, indicated that the composts were non-toxic and stable.

The stimulation of radicle germination with IG exceeding 100% is due to the stable organic matter content, the richness of humic substances and the mineral elements during the ripening phase (Yangui *et al.*, 2009).

Acknowledgements

The authors thank Yannick AWONO for supplying the wood ash, the Agricultural Research Institute for Development (IRAD) Cameroon for assistance with the chemical analysis.

Conclusion

Co-composting green waste and wood ash allowed to obtain composts with higher pH conferring higher buffering capacity, thus reducing the quantity of compost needed to treat soil acidity.

The composts had greater macronutrients and micronutrients content along no issue on heavy metals content. Wood ash did not significantly impair microbial biomass, cellulase and phosphatase activities, and was not toxic to maize seed and seedlings.

Therefore, Co-composting green wastes with wood ash as an additive could be recommended to remediate soil acidity and base deficiency and boost the soil microbial pool in tropical agricultural soils. Additional studies are needed to evaluate the applicability of the produced composts for sustainable agriculture in the tropics.

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