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RESEARCH ARTICLE

Comparative short-term effects of sewage sludge and its biochar on soil properties, maize growth and uptake of nutrients on a tropical clay soil in Zimbabwe

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Abstract

Soil application of biochar from sewage could potentially enhance carbon sequestration and close urban nutrient balances. In sub-Saharan Africa, comparative studies investigating plant growth effect and nutrients uptake on tropical soils amended with sewage sludge and its biochar are very limited. A pot experiment was conducted to investigate the effects of sewage sludge and its biochar on soil chemical properties, maize nutrient and heavy metal uptake, growth and biomass partitioning on a tropical clayey soil. The study compared three organic amendments; sewage sludge (SS), sludge biochar (SB) and their combination (SS+SB) to the unamended control and inorganic fertilizers. Organic amendments were applied at a rate of 15 t ha^{-1} for SS and SB, and 7.5 t ha^{-1} each for SS and SB. Maize growth, biomass production and nutrient uptake were significantly improved in biochar and sewage sludge amendments compared to the unamended control. Comparable results were observed with F, SS and SS+SB on maize growth at 49 d of sowing. Maize growth for SB, SS, SS+SB and F increased by 42, 53, 47, and 49%, respectively compared to the unamended control. Total biomass for SB, SS, SS+SB, and F increased by 270, 428, 329, and 429%, respectively compared with the unamended control. Biochar amendments reduced Pb, Cu and Zn uptakes by about 22% compared with sludge alone treatment in maize plants. However, there is need for future research based on the current pot experiment to determine whether the same results can be produced under field conditions.

Keywords: maize growth, nutrient uptake, sludge biochar, soil chemical properties

1. Introduction

Low and declining soil fertility coupled unreliable rainfall constrain crop yields in smallholder cropping systems in sub-Saharan Africa (SSA), resulting in low yields (<1.5 t ha^{-1}) compared to 12 t ha^{-1} attained in commercial sector (Mtambanengwe and Mapfumo 2009). Research on soil fertility in smallholder cropping systems in SSA focussed on three options: (1) harnessing biological nitrogen fixation by incorporating leguminous crop and agroforestry species

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(Mapfumo *et al*. 1999), (2) use of local available resources such as animal manure, leaf litter, termitaria, and crop residues, and (3) use of inorganic fertilizers, and their combination with organic fertilizers. Although yield increases have been reported in most cases, their adoption remains low due to several constraints including availability, quantity and quality (Mapfumo and Giller 2001).

Earlier efforts to improve soil fertility were limited to rural farmers, thus excluded urban and peri-urban agroecosystems, an emerging source of livelihoods and food security in Africa. Sewage sludge has become an important nutrient resource for urban and peri-urban farmers in Zimbabwe (Katanda *et al*. 2007), largely because, compared to inorganic fertilizers which are expensive, sewage sludge is readily and freely available from wastewater treatment systems. However, high levels of pathogens and heavy metals in sewage sludge pose significant environmental and public health risks. Pyrolysis of sludge into biochar, and subsequent application to soils could potentially reduce the risks (Fytili and Zabaniotou 2008) while simultaneously sequestering soil carbon and enhancing soil quality (Gwenzi *et al*. 2015). Biochar, a carbon rich, fine-grained, porous substance has shown to have several properties that could enhance plant growth and heavy metal adsorption. Biochar feedstocks include crop residues, wood waste, yard trashes, manures and sewage sludge (Duku *et al*. 2011; Gwenzi *et al*. 2015).

Pyrolysis of sludge into biochar can form part of sustainable integrated fertility management for improved crop productivity and food security, while minimizing potential public health risks associated with the use of raw sludge in urban and peri-urban areas of sub-Saharan Africa. Available studies on the effects of biochar were predominantly conducted in other continents such as Australia, South America, Europe, North America, and Asia (Glaser *et al*. 2002; van Zwieten *et al*. 2010; Haefele *et al*. 2011), while limited data are available in Africa. Most of the studies focused on the effects of biochar on agronomic performance, carbon sequestration, soil fertility, and greenhouse gas emissions. Comparative studies investigating the effects of biochar to its raw feedstocks are still limited especially in Africa. Moreover, little research has been conducted on the effects of sludge biochar on soil properties, plant growth and nutrient uptake on typical tropical soils as those in sub-Saharan Africa. Few available studies on sludge biochar conducted in China and Australia focussed on effects of pyrolysis temperature on nutrient content (Hossain *et al*. 2011), and garlic yield and heavy metal accumulation (Song *et al*. 2014), respectively. Given that urban and peri-urban farmers in SSA are using sewage sludge as a fertilizer amendment, there is need to find ways to reduce the health risks from pathogen and heavy metals while at the same time increasing food security at the household level. The main objective was to compare the short-term effect of sludge and its biochar derivative on maize growth, heavy metal uptake and soil chemical properties.

2. Results

2.1. Chemical characteristics of soil, sewage sludge and biochar

The soil used for this study had inherently low nutrient content compared to both the sludge and biochar. The soil had a near-neutral pH coupled with an electrical conductivity value of 0.35. In addition, the soil had the least total N, P and Ca which were consistent with the least cation exchange capacity (CEC) compared to biochar and sludge. However, the soil had a considerable amount of K and Mg (Table 1). Organic amendments used had appreciable levels of Mg and Ca but contained low potassium. Sewage sludge had higher total N and %C (C percent) than biochar while the total P and K of the two amendments were similar. A lower electrical conductivity (EC) value was observed in biochar (1.1 dS m^{-1}) than in sewage sludge (2.85 dS m^{-1}) (Table 1). Biochar had about a unit higher pH than that of sludge. The concentrations of Pb, Cu, Ni, and Zn in the biochar were similar to those of the sludge.

2.2. Maize growth and biomass partitioning

The final plant height and total number of leaves for biochar and biochar+sludge were comparable to those of inorganic fertilizer (compound D (7% N:14% P_2O_5:7% K2O)+ammonium nitrate (AN, 34.5% N)) and sewage sludge (Fig. 1). For both height and number of leaves, biochar alone showed no significant differences with the unamended control during the early stages of plant growth until around day 21. Thereafter, a sudden increase in growth is observed. As expected, the unamended control had significantly lower growth response in terms of both height and leaves productivity than the other treatments (Fig. 1).

Inorganic fertilizer (compound D+AN) and sludge+AN treatments attained the highest ($P<0.05$) total biomass (shoot+root) while the unamended control had the least. Sludge+biochar and biochar had similar total biomass (Fig. 2-A). Raw sludge had the highest shoot biomass (>70 g pot^{-1}) while unamended control attained the least shoot biomass (~10 g pot^{-1}). Shoot dry biomass for treatments involving biochar (sludge+biochar, biochar) were comparable to those of inorganic fertilizer (compound D+AN) but lower than raw sludge (Fig. 2). However, there are contradictions between the trend for total biomass and those for biomass partitioning into roots and shoots across