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Microbial response to the restoration of a Technosol amended with local organic materials

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ABSTRACT

Farmers of western Rwanda directly cultivate tantalite mine soils due to land scarcity with sole reliance on farmyard manure (FYM) as fertilizer. However, there is limited knowledge of its effects on soil microbial properties. We therefore investigated the effects of FYM, *Canavalia brasiliensis* and *Tithonia diversifolia* biomass, and *Markhamia lutea* leaf litter on C and N mineralization and microbial properties in a Technosol (unrestored tantalite mine soil) and an arable soil in a laboratory study. Fresh soils (0–20 cm) were amended and incubated for twelve weeks. C mineralization was measured weekly by alkali trap while N mineralization and microbial properties were determined from the incubated soils after 4, 8, and 12 weeks of incubation. The amendments substantially increased ($P < 0.01$) CO_2 efflux, N mineralization, and microbial properties compared with non-amended soils. Canavalia and FYM mineralized N while Markhamia and Tithonia immobilized it. Canavalia had the greatest increase in CO_2 efflux, net N mineralization, and microbial biomass C and N by 340%, 30–140%, 240–600%, and 240–380%, respectively, compared to non-amended soils after four weeks. Tithonia had the largest increase in ergosterol content by roughly 240% and the greatest contribution of ergosterol to microbial biomass C with marginal effects on microbial biomass C and N. The Technosol had the utmost increases in microbial properties and C and N mineralization, suggesting a greater response to the amendments and seems to have a high potential for quick restoration of soil productivity. The effects of each amendment also suggest optimum benefits through combined use.

1. Introduction

Columbite-tantalite (coltan) mining begun in Rwanda during the early twentieth century largely in an artisanal manner (MINIRENA, 2010) and created huge tracts of degraded mine wastelands, particularly in the Gatumba Mining District of western Rwanda. Due to high population density coupled with land scarcity, farmers resident in this mining concession directly cultivate the tantalum mine wastelands alongside arable and other marginal lands without prior restoration. The problem is aggravated by poor soils with high acidity (pH < 5.5) and nutrient mining (Yamoah et al., 1990) caused by minimal nutrient inputs coupled with continuous nutrient export through crop harvests. Due to limited access to mineral fertilizers, the farmers rely solely on scanty poor-quality farmyard manure (FYM) to improve crop yields.

Yet, there is an abundance of multi-purpose but under-utilized plant species, which could be used to improve soil quality. One of such species is *Tithonia diversifolia* (Hemsley) A. Gray, also called Mexican sunflower. *Tithonia diversifolia* is abundant in East Africa and is known for its ability to scavenge and concentrate nutrients in its biomass which has proved useful in compost quality enhancement (Drechsel and Reck, 1998), crop yield increase (Gachengo et al., 1999; Jama et al., 2000; Olabode et al., 2007), and P mineralization (Kwabiah et al., 2003). Further, the legume cover crop *Canavalia brasiliensis* (Mart. ex Benth.) is also prevalent in Rwanda. It is reported to be a high N_2-fixing and high biomass-producing legume recommended for the tropical highlands of Rwanda (Yamoah and Mayfield, 1990). *Canavalia brasiliensis* has been widely studied for its contribution to C and N sequestration and crop improvement in Brazilian agro-ecosystems (Carvalho et al., 2014; Cobo et al., 2002). Further, *Markhamia lutea* (Benth.) K. Schum., one of the five top-priority agroforestry species in tropical

Abbreviations: ADF, Acid detergent fiber; FYM, Farmyard manure; HPLC, High Performance Liquid Chromatography; MAP, Months after planting; MBC, Microbial biomass carbon; MBN, Microbial biomass nitrogen; NDF, Neutral detergent fiber.

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Africa (Owino, 1992), which is almost extinct in Gatumba Mining District (C. Rwabahizi, personal communication, May 6 2013), is said to contain substantial amounts of plant nutrients (Silas et al., 2012). So far, the potential for these native species to improve soil microbial properties, particularly in mine soils has been least explored.

Recent studies (Ndoli et al., 2013) conducted on the (columbite-tantalite) tantalite mine soils of Gatumba revealed that the application of *Tithonia diversifolia* biomass at 5 ton ha^{-1} dry matter mixed with Minjingu rock and triple super phosphates in different ratios produced two-fold dry matter biomass and about three-fold soybean (*Glycine max* (L.) Merr) grain yield on pure tantalum pegmatite spoil compared to a mix of the spoil and a clay-rich Lixisol horizon. Additionally, a survey conducted in the Gatumba Mining District showed 27%, 10%, 16%, and 14% increases in the yields of climbing bean (*Phaseolus vulgaris* L.), cassava (*Manihot esculenta* Crantz), *Colocasia* (*Colocasia esculenta* (L.) Schott, and sweet potato (*Ipomea batatas* (L.) Lam.) on the mine soils fertilized with FYM compared to un-mined soils. (Diogo 2012, unpublished). However, the extent of microbial proliferation and mineralization of these amendments in the mine soils is unknown. Interestingly, the tantalum mine soils are dominantly pegmatite substrates and contain very low amounts of Zn, Cd, Pb, Cu, Cr, Ni, U, and As, which are either at or below continental crust averages (Flügge et al., 2008; Lehmann et al., 2008). Analysis of sediments in adjacent streams also revealed contents below WHO standards (Flügge et al., 2008). The mine soils are however, enriched with potassium (K) (Lehmann et al., 2014). This bestows the spoils with great prospects for restoration towards sustainable crop production.

Globally, reclamation laws require the salvage and subsequent replacement of top and subsoils on mine spoils before revegetation to restore biological activity and promote plant succession (Larney et al., 2005; Zipper et al., 2013). Thus, mine soils restored with top- and subsoil replacement are called *graded* mine soils while their counterparts without replacement are *ungraded* mine soils (Akala and Lal, 2001). In this study, we investigated the capacity of the cultivated tantalite mine soils to mimic *graded* mine soils to enhance rapid snap back towards pre-mine or similar conditions. A previous study on microbial properties of the tantalite mine soils (Neina et al., 2016) revealed that the soils hold initial microbes required to kick-start nutrient cycling. We specifically aimed to investigate (1) the increase in microbial biomass and (2) C and N mineralization in a tantalite mine soil, termed as Technosol (IUSS Working Group WRB, 2014), amended with FYM, biomass of *Canavalia brasiliensis* and *Tithonia diversifolia* as well as *Markhamia lutea* leaf litter. We further postulated that local organic materials are a feasible option to enhance the biological quality of the Technosols in Gatumba Mining District by stimulating microbial properties and activity to release essentials plant nutrients. However, the amendments may exert distinctive effects on microbial biomass C and N turnover because of their unique biochemical characteristics.

Table 1
Mean values (n = 5) of initial properties of the arable soil and Technosol from the Gatumba Mining District, western Rwanda used for the experiment.

Parameter	Unit	Soils	
		Arable soil	Technosol
pH(H_2O)		4.9	5.6[a]
Bulk density	($g\,cm^{-3}$)	1.3	1.2
Clay	%	50	33
Total carbon	($mg\,g^{-1}$ soil)	10.9	10.2
Total nitrogen	($mg\,g^{-1}$ soil)		
C/N	($mg\,g^{-1}$ soil)	11	12
Total phosphorus	($mg\,g^{-1}$ soil)	0.55	0.42
C/P		18	19
Resin-P	($\mu g\,g^{-1}$ soil)	0.8	0.5
Bray-I P	($\mu g\,g^{-1}$ soil)	7.0	7.1
Dithionite-extractable Al	($mg\,g^{-1}$ soil)	4.9	4.2
Microbial biomass carbon	($\mu g\,g^{-1}$ soil)	134	126
Microbial biomass nitrogen	($\mu g\,g^{-1}$ soil)	29	47
Microbial biomass phosphorus	($\mu g\,g^{-1}$ soil)	9	9
Microbial biomass C/N		4	4
Ergosterol	($\mu g\,g^{-1}$ soil)	0.21	0.25

[a] Contained an outlier of pH 8 in sample from a plot applied with of wood ash during a cassava trial that had been installed. The mean pH without the outlier was 5.0 (Neina et al., 2016).

2. Materials and methods

2.1. Soils

To unravel the query presented earlier, we selected an arable soil and a Technosol from Kavumu village in the Gatumba Mining District, western Rwanda. The arable soil (Fig. 1) is a clayey loam from a farm that had been cultivated with climbing beans, green peas (*Pisum sativum* L.), sweet potatoes and cassava in a mixed pattern and amended with FYM usually before planting. The Technosol (Fig. 1) is a sandy clay loam located in the Kavumu coltan quarry. It had a slightly higher pH than the arable soil but slightly lower soil organic carbon (SOC), total N, and microbial biomass C (MBC) contents (Table 1). The residents of Gatumba Mining District cultivated the Kavumu coltan quarry aside experiments installed by the Coltan Environmental Management project. From March to July 2013, climbing beans and sweet potatoes had been cultivated on the site with FYM and *Tephrosia vogelii* Hook. f. biomass (FYM: 5–10 t dry matter ha^{-1}; FYM + Tephrosia (1:1): 5–10 t dry matter ha^{-1}) as amendments (C. Numuhire, unpublished). At the time of soil sampling, a cassava trial was installed on the site. The

Fig. 1. The arable soil and the Technosol from the Gatumba Mining District of western Rwanda used for this study.