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Utilization of Sanitized Human Excreta and Wood Ash for Establishing Multipurpose *Ficus Thonningii* Blume in a Degraded Tantalum Technosol

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ABSTRACT: The inclusion of native trees in mine land reclamation has been promoted over the years yet that of high-value multipurpose species for people's livelihoods has been overlooked. Also, studies utilizing human excreta (HE), i.e. fecal matter, (FM) and human urine fertilizer HUF), and wood ash (WA) in land reclamation are scarce. Yet, these are indispensable in areas with a limited supply of organic materials and high demand for natural resources. This study evaluated the effects of HE and WA on the growth and establishment of *Ficus thonningii* Blume (ficus) in a pegmatite-rich tantalum Technosol. Hardwood cuttings of ficus from homesteads in Western Rwanda were planted in 20.4 × 19 cm diameter pots containing 5 kg forest soil (FS) and 6 kg Technosol. Five treatments including No amendment; HUF alone (100 mL/pot); HUF+WA (100 mL + 60 g/pot); FM (200 g/pot); and FM+WA (200 g + 60 g/pot) were prepared in ten replicates each. Plant height, number of leaves, shoot and root biomass were determined after five and seven months after planting. The HE and WA treatments significantly increased ($P = 0.003$) ficus height (FS = 39 – 42 cm and Technosol = 31 – 34 cm) after seven months. Shoot biomass weights ranged from 17 – 21 g in the FS and 10 – 16 g in the Technosol. Ficus exhibited an efficient rooting system that stabilized the loose particles of the Technosol, suggesting the potential of using ficus, HE, and WA in degraded mine soil reclamation in future research.

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Several approaches have been used to reclaim degraded mine lands depending on the end land use. These include afforestation and reforestation with or without soil amendments (Gardner *et al*., 2010; Larney and Angers, 2012) or direct cultivation with the application of inorganic fertilizer and other soil amendments. The choice of a reclamation approach is often dictated by factors such as landscape, soil properties (Shrestha and Lal, 2011; Tejada and Benítez, 2014), and biological factors including the need for fast-growing species such as eucalyptus (Madejón *et al*., 2016), nitrogen-fixing (Franco and Faria, 1997). So far the native tree species that have been widely used are non-multipurpose species such as *Albizzia sp*. and *Tectona grandis* L.f. (Singh *et al*., 2004; Mulizane *et al*., 2005). Sadly, no afforestation technique takes cognizance of the future land use change of reclaimed sites in light of population explosion and increasing demand for land, the livelihoods of local people, biodiversity conservation, as well as the multipurpose functions of tree species used in reclamation. The inclusion of multipurpose tree species in mine land reclamation may deliver more utility by providing ecosystem goods and services, provision of the livelihood support base of local people and other environmental benefits. For mine sites located in areas where people depend heavily on natural resources, it is essential to include multipurpose native tree species to provide the aforementioned services. This is particularly useful where the mine soils do not contain substantial amounts of toxic elements. *Ficus thonningii* (Blume) is a multipurpose tree species native to tropical Sub-Saharan Africa. It is a drought-tolerant tree used for food, fodder, raw materials for domestic use (Biggelaar and Gold, 1996), bee forage, fuelwood, timber and has the potential to improve soil fertility (Berhe *et al*., 2013). Other benefits of ficus include its ability to improve soil fertility and most importantly the absence of allelopathic effects on crops (Gebremikael, 2018). For instance, a study on the importance of ficus in soil fertility improvement involving over three-decade-old ficus stands in Gondar Zuria, Ethiopia showed almost 2-fold nitrogen and 1.3% more organic carbon in the top 10 cm of soils under tree canopy compared to soils outside tree canopies. Ficus is easily propagated by cuttings, mature in 1.5 to 2 years and produces high biomass of high nutritive value (Gebremikael, 2018). This makes it a good choice for inclusion in mine land reclamation. However, little is known about the survival of ficus on extremely harsh soil conditions of mine sites. Further,

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studies involving human excreta and WA in mine land reclamation are scarce although many have been used for crop production (Larney and Angers, 2012).

Previous studies have demonstrated the beneficial impacts of several organic amendments used in mine soil reclamation with reports of considerable improvements in chemical, physical and microbial soil properties (Gardner *et al*., 2010; Larney and Angers, 2012). Although organic soil amendments improve tree growth, carbon and nitrogen, pools the effects vary considerably because of differences in composition (Madejón *et al*., 2016). However, in places with a limited supply of organic materials, the need for reclamation can be daunting and can impede the success of reclamation programs in extremely degraded nutrient-poor mine soils. Thus, human excreta (feces and urine) and wood ash (WA) which have less competitive uses and are readily available could be conveniently incorporated into mine land reclamation. This study seeks to investigate the effects of fecal matter, human urine, and WA on the growth and establishment of *F. thonningii* (ficus) cuttings in a pegmatite-rich coarse-textured but nutrient-poor tantalum mine soil. It contrasts the focus of many studies that have used native species for reclamation with the aim of mainly restoring the taxonomic diversity instead of the functional diversity of species to provide the requisite ecosystem services (Aerts and Honnay, 2011). Where the use of plant nutrients in human excreta is limited by health risks and culture barriers, its use in reclamation could be an option to reduce environmental pollution and enhance environmental management in mining. This is a preliminary study and is expected to be replicated under field conditions. Agronomic trials involving some of the pegmatite-rich tantalum mine soils applied with tithonia (*Tithonia diversifolia* (Hemsley) A. Gray) biomass, Minjingu rock phosphate, and inorganic fertilizer significantly increased soybean biomass as well as N, P and K uptake (Ndoli *et al*., 2013). In another study, sandy clay loam mine soils from the same area showed a higher potential for quick rehabilitation in terms of microbial properties and carbon, nitrogen and phosphorus mineralization following the application of tithonia and canavalia (*Canavalia brasiliensis* (Mart. ex Benth.)) biomasses (Neina *et al*., 2016a, 2016b).

MATERIALS AND METHODS

Experimental site, soils and amendments used: The experiment was conducted in the Gatumba Mining District (longitudes 29°37" and 29°40" E and latitudes 1°53" and 1°56" S) in the Western Province of Rwanda. The rainfall distribution is bimodal averaging 1320 - 2400 mm p.a. Average temperatures range between 18 °C and 21 °C. Soils used for the experiment comprised the topsoil of a Lixisol from an old mine site afforested with eucalyptus (*Eucalyptus spp.*) for over three decades (i.e. forest soil, FS) and a tantalum mine soil (Technosol) comprising a mixture of a coarse sandy pegmatite (predominantly quartz, feldspars, and Muscovite) and a sandy clay loam mine soil mixed at a ratio of 5:1. The mine spoils were obtained from a tantalum mine quarry (Fig. 1) located at Rusumo village in the Gatumba Local Government Administrative sector. Previous studies on the pegmatite-rich tantalum mine spoil revealed very low amounts of Zn, Cd, Pb, Cu, Cr, Ni, U, and As (Flügge *et al*., 2008; Lehmann *et al*., 2008) and enrichment of potassium (K) (Lehmann *et al*., 2014). Human excreta comprises fecal matter (FM) and urine or human urine fertilizer (HUF). The HUF and WA used for this experiment were obtained from a secondary school (*Association de Development pour Education Culturel,* College ADEC) in Rusumo village. The HUF was stored in tightly closed jerry cans at 22°C for two months before use. The FM, which had been dehydrated and composted with rice straw, sawdust and WA to deactivate pathogens, was obtained from a urine-diverting toilet in Kigali, Rwanda. Studies show that this method sanitizes human excreta for safe use (Jönsson *et al*., 2004).

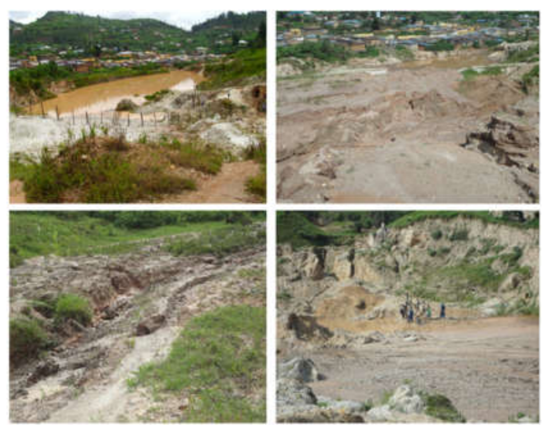

Fig. 1: The tantalum quarry from which the Technosol was obtained. It is located at Rusumo village in the Gatumba sector, western Rwanda

Sample analysis: The soils and amendments were analyzed for selected properties by standard methods (Okalebo *et al*., 2002). Available P was extracted using the method of Bray and Kurtz (1945) and subsequently determined colorimetrically while the pathogenic properties of the excreta were analyzed using the methods of Guiraud (1998) at the University of Rwanda. Residual soil properties and plant biomass were not conducted because the study focused initially on the establishment of ficus in the degraded pegmatite-rich Technosol.

Experimentation: Hardwood stem cuttings (20 cm long) of ficus were obtained from homesteads in the study area and rinsed with dilute white vinegar before planting. The experiment comprised five treatments: (i) Control (No amendment); (ii) HUF alone (100 mL/pot); (iii) HUF+WA (100 mL + 60 g/pot); (iv) FM (200 g/pot); and (v) FM+WA (200 g + 60 g/pot) prepared in ten replicates each. Plastic pots of 20.4 cm diameter, 19 cm height were filled with 5 kg of the FS and 6 kg of the Technosol. Here, the volume of soil in the pots and its effect on root development was more important. The soils were wetted to water holding capacity (WHC) and allowed to equilibrate for at least 24 h before planting. The HUF was diluted at a ratio of 3:1 (Jönsson *et al*., 2004) before application. Subsequently, the pots were arranged under a shed in a randomized complete block design. The planted cuttings were watered daily using 20% WHC. After five months of planting, five plants were randomly sampled and the plant height was measured and the number of leaves counted. During each sampling period, the plants were gently removed from the pots (Fig. 2) and the soil particles are shaken off from the roots. The roots were separated from the shoots, cleaned, and dried in an oven at 70°C to determine the oven-dry weight. This was repeated at seven months after planting. The experiment was originally designed to last for nine months but was cut short by harsh environmental conditions. Therefore, data for the remaining period and residual soil properties could not be considered in the report. The data were checked for suitability for the analysis of variance (ANOVA) and where necessary, they were log-transformed before analysis. A two-way ANOVA was used to process the data using *Soil* and *Treatment* as the independent factors with 5% level of significance under missing data mode in SPSS version 20 (IBM-SPSS Inc., USA).

RESULTS AND DISCUSSION

Soils and amendments: The FS had almost 6-fold OC content than the Technosol (Table 1). In contrast, the Technosol had 1.3 pH units and 1.1 mg kg^{-1} more phosphorus but did not contain any nitrogen. All the amendments had alkaline pH, particularly the WA. The FM and WA were enriched with phosphorus (Table 1) and also had about 10% OM content while the HUF had nitrogen content similar to the typical global average per capita fecal nitrogen per annum (Jönsson *et al*., 2004). The hygienic quality of the human excreta revealed that no viable *E. coli*, Salmonella, and Shigella were detected in the excreta. The total coliforms and Streptococcus were less than 1 cfu/100 mL (Table 2). However, total flora aerobic mesophiles in the FM were 3000 times that in the HUF (Table 2) while the aerobic bacteria present in the FM were about 2 to 2.7 times the amounts in HUF. These properties of the amendments are essential and influenced the growth of ficus in the Technosol. The aim of ecosan is to close the nutrient loop between sanitation and agriculture by (1) separating wastewater into different flow characteristics (e.g. feces, urine, and greywater) to enhance treatment and utilization, and (2) minimize the dilution of the streams to reduce pathogen survival (Esrey *et al*., 1998). Thus, the excreta used in this study were products of ecosan. The hygienic quality was good, suggesting that the most dreaded pathogens were either absent or virtually absent in the human excreta. Generally, total coliforms, fecal coliforms, *Escherichia coli* (*E. coli*), fecal streptococci, and enterococci have been suggested to be the most commonly used indicators for fecal contamination (Ashbolt *et al*., 2001). Incidentally, the excreta did not any *E. coli* while total coliforms and fecal streptococci were short of 1 cfu/100 ml (Table 2). Similar results were obtained by Vinnerås *et al.* (2003) in the deactivation of indicator organisms in FM using a quaternary mixture of 15% peracetic acid, 15% hydrogen peroxide and 30% acetic acid. The FM used in the study was conditioned with WA and rice straw to enhance dehydration followed by drying whereas the HUF was stored. These methods have been tested and recommended as low-cost techniques for sanitizing human excreta (Jönsson *et al*., 2004; Vinnerås *et al*., 2008). Moreover, the excreta contained the major nutrients essential for plant nutrition.

Ficus height, number of leaves and biomass weights: By the fifth month of planting, 8% and 24% of the cuttings died in the FS and Technosol, respectively. The height of ficus was largely influenced ($P = 0.003$) by the application of FM, FM+WA, and HUF+WA and occurred in the order FM > FM+WA > HUF+WA > HUF > Control in the FS and FM+WA > FM > HUF+WA > HUF > Control in the Technosol (Table 3). By the seventh month, the effect of the amendments on ficus height was still evident ($P = 0.001$). This time, the order of effects of the amendments in the FS was similar to that in the Technosol at five months. Interestingly, the combined excreta and WA treatments seemed important in the Technosol whereas those of the FM alone was important in the FS. The human excreta produced ficus heights ranging from 39 – 42 cm in the FS and 31 – 34 cm in the Technosol after seven months of planting. This difference may be attributed to the conditioning effects of FM on soil properties of the sandy clay FS and the difference in allocation of nutrients in both soils as ficus had thicker roots (see later sections) in the Technosol. Higher growth rates have been observed in native trees grown in mine soils elsewhere (Román-Dañobeytia *et al*., 2015; Madejón *et al*.,

2016) although native tree species are generally known to grow more slowly than most exotic species (Mulizane *et al*., 2005). Nonetheless, species characteristics and the variations in soil properties cannot be discounted. At five months, the number of leaves was influenced by *Soil* where the FS produced about 4 more leaves ($P = 0.017$) than the Technosol (Table 3). By the seventh month, *Soil* × *Treatment* interacted ($P < 0.001$) where FM+WA produced about 25 more leaves in the FS compared to the Technosol (Table 3). Treatment effects ($P < 0.001$) were in the order FM+WA > HUF+WA > FM > HUF > Control in the FS and HUF+WA > FM > HUF > FM+WA > Control in the Technosol. The biomass weights (roots and shoots) after five months revealed *Soil* × *Treatment* interaction effects ($P = 0.002$), effects of *Soil* ($P < 0.001$) and *Treatment* ($P < 0.001$) for the root dry weight (Table 4). The mean root dry weight was 8.6 g higher in the Technosol, with larger weights mostly associated with the combined excreta and WA treatments. By the seventh month, only the effect of *Treatment* ($P = 0.001$) was found. This occurred in the order FM+WA > FM > HUF+WA > HUF > Control in both soils. In contrast, the experiment did not produce effects on the shoot dry weight after five months but in the seventh month, *Soil* × *Treatment* interaction ($P = 0.017$) was found whereby large effects of combined excreta and WA treatments (FM+WA, HUF+WA) occurred in the FS compared to large effects of fecal matter and WA (FM, FM+WA) treatments in the Technosol.

Fig. 2: (A) Ficus plants in the Technosol applied with fecal matter, (B) unamended Technosol, (C) FS applied with fecal matter, and (D) ficus plants uprooted from Technosol showing thick and short roots.

This could probably be due to a lag phase in the establishment of the cuttings. The *Treatment* effects followed the same trend, giving biomass weights ranging from 17 – 21 g in the FS and 10 – 16 g in the Technosol. These agree with those found by Madejón *et al*. (2016) although the treatments comprised large and repeated doses of compost (>2 kg) compared to what pertained in this study. The root biomass and the root: shoot ratio generally decreased with time in all the treatments except for the non-amended soils of both soils. After five months, root: shoot ratio was about 0.8 g higher ($P = 0.012$) in the Technosol (Table 4).

Table 1. Properties of the soils, the fecal matter, wood ash, and HUF (N = 4 ± one standard deviation) used in the pot experiment

Parameter	Forest soil	Technosol	Fecal matter	Wood ash	HUF
pH (water)	4.6 ± 0.0	5.9 ± 0.0	7.4 ± 0.0	12.0 ± 0.0	8.6 ± 0.0
Organic C (g kg^{-1})	29.1 ± 0.3	5.1 ± 0.7	61.9 ± 1.1	-	NM
Total N (g kg^{-1})	2.0 ± 0.0	0.0 ± 0.0	0.28	-	2.0 ± 0.0
Avail. P (mg kg^{-1})	2.8 ± 0.6	3.9 ± 0.9	-	-	-
Total P (g kg^{-1})	520 ± 39.9	NM	5.4 ± 0.5	11.4 ± 0.5	NM

NM: not measured

Table 2. Pathogen load in sanitized fecal matter and HUF used for the study (N = 3)

Pathogenic properties	Fecal matter	HUF
Total flora aerobic mesophiles (37ºC after 24 h), Plate Count Agar	3×10^3 cfu/ml	<1 cfu/ml
Total flora aerobic mesophiles (22ºC after 72 h), Plate Count Agar	3×10^3 cfu/ml	<1 cfu/ml
Total coliforms (37ºC after 48 h), TERGITOL-7	<1 cfu/100 ml	<1 cfu/100 ml
Total coliforms (44ºC after 48 h), TERGITOL-7	<1 cfu/100 ml	<1 cfu/100 ml
E. coli (44ºC after 24 h), PEPTON Water	Absent	Absent
Streptococcus (37ºC after 48 h), SLANETZ	<1 cfu/100 ml	<1 cfu/100 ml
Bacteria RSA (Aerobic) (37ºC after 24 h), SPS Agar	44 cfu/20 ml	<24 cfu/20 ml
Bacteria RSA (Aerobic) (37ºC after 24 h), SPS Agar	52 cfu/20 ml	<19 cfu/20 ml
Salmonella & Shigella (37ºC after 24 h), SS Agar XLD	Absent	Absent

By the seventh month, the root: shoot ratio was similar in both soils and revealed *Soil* by *Treatment* interaction effects ($P = 0.034$) whereby slightly larger ratios occurred in Control and HUF of the FS and Control and HUF+WA of the Technosol. The observations suggest that human excreta and WA can enhance the growth and establishment of ficus cuttings in pegmatite-rich nutrient-poor Technosols. It is evident from the plant growth parameters that the effects of FM, FM+WA, and HUF+WA were higher (Tables 3 and 4), particularly for plant height and biomass weights compared to HUF and un-amended soils.

Table 3. Mean (N ≤ 5 ± one standard deviation*) of the height and number of leaves of ficus at five and seven months after planting.

Treatment	Height (cm)		Number of leaves	
	5 Months	7 Months	5 Months	7 Months
Forest soil				
Control	19.7 ± 4.2b	18.4 ± 7.1d	48.0 ± 14.8	17.0 ± 3.7
FM	26.8 ± 8.9a	42.3 ± 14.1a	68.2 ± 21.5	50.6 ± 14.6
FM+WA	25.4 ± 12.3a	38.9 ± 9.4a	42.3 ± 24.0	62.5 ± 7.5
HUF	17.3 ± 6.2b	20.3 ± 3.3b	44.2 ± 32.2	26.0 ± 5.6
HUF+WA	25.5 ± 5.6a	38.6 ± 15.2a	32.2 ± 11.8	60.4 ± 14.0
Mine soil				
Control	17.2 ± 2.6b	21.5 ± 7.4b	42.0 ± 19.7	30.7 ± 5.5
FM	31.8 ± 5.9a	31.0 ± 7.1a	39.5 ± 10.8	50.5 ± 7.9
FM+WA	32.2 ± 6.8a	33.4 ± 8.0a	45.0 ± 1.4	37.8 ± 13.7
HUF	18.3 ± 3.2b	28.7 ± 7.8b	43.8 ± 11.9	46.2 ± 6.1
HUF+WA	19.6 ± 4.5b	34.1 ± 7.9a	42.7 ± 7.5	52.0 ± 11.0
Probability values				
Soil	*NS*	*NS*	*0.017*	*NS*
Treatment	*0.003*	*0.001*	*NS*	*<0.001*
Soil × Treatment	*NS*	*NS*	*NS*	*<0.001*

*Some plants died

Specifically, the HE and WA treatments were important for ficus height and root weight in the Technosol whereas FM and WA treatments promoted shoot weight. This is due to the presence of substantial amounts of Ca, K, Mg and P and very limited amounts or absence of nitrogen. The WA nutrients combined with those supplied by the nitrogen-rich excreta produced the observed rates. Moreover, the effects of initial soil pH (relatively higher Technosol pH) coupled with the effects of mineralization processes in the FM could have produced the observed effects in the Technosol. This is essential as the initial soil properties, particularly soil pH, also influence plant nutrition and plant establishment (Madejón *et al*., 2016). Moreover, the FM acts as a soil conditioner when applied to soil because of its OM content which could improve physical soil properties to give the greatest benefits to plants (Jönsson *et al*., 2004).

Table 4. Mean (N ≤ 5 ± one standard deviation*) of oven-dry root and shoot weights and root: shoot ratio of ficus at five and seven months after planting.

Treatment	**Root weight (g)**		**Shoot weight (g)**		**Root: shoot ratio**	
	5 Months	**7 Months**	**5 Months**	**7 Months**	**5 Months**	**7 Months**
Forest soil						
Control	5.7 ± 2.3b	6.9 ± 2.2b	4.5 ± 2.8	3.4 ± 0.7b	2.0 ± 1.0	2.1 ± 0.6a
FM	6.3 ± 2.9b	18.4 ± 7.0a	7.3 ± 2.7	17.2 ± 6.2a	1.2 ± 0.4	1.1 ± 0.2b
FM+WA	8.8 ± 9.7a	21.1 ± 5.8a	7.0 ± 3.4	20.7 ± 9.2a	1.1 ± 0.3	1.1 ± 0.4b
HUF	4.3 ± 1.3c	10.7 ± 4.5b	2.8 ± 0.9	7.0 ± 3.9b	1.8 ± 0.7	1.7 ± 0.5a
HUF+WA	9.5 ± 3.2a	14.5 ± 4.2a	6.1 ± 1.8	20.5 ± 4.9a	1.8 ± 0.4	0.8 ± 0.3b
Mine soil						
Control	9.3 ± 2.4b	12.4 ± 5.2b	5.7 ± 1.8	6.6 ± 0.7c	1.7 ± 0.2	1.8 ± 0.7a
FM	17.1 ± 4.7a	14.9 ± 3.5a	7.0 ± 1.3	15.4 ± 4.5a	2.7 ± 0.6	1.0 ± 0.4b
FM+WA	20.9 ± 4.2a	19.4 ± 8.9a	10.1 ± 3.7	15.5 ± 2.9a	2.3 ± 1.3	1.2 ± 0.4b
HUF	9.4 ± 5.8b	10.2 ± 1.5b	5.0 ± 2.1	10.8 ± 2.0b	2.7 ± 1.0	1.0 ± 0.3b
HUF+WA	20.7 ± 6.4a	14.7 ± 7.0a	10.4 ± 6.4	10.4 ± 5.6b	2.7 ± 2.9	1.7 ± 1.1a
Probability values						
Soil	*<0.001*	*NS*	*NS*	*NS*	*0.012*	*NS*
Treatment	*<0.001*	*0.001*	*NS*	*<0.001*	*NS*	*0.023*
Soil × Treatment	*0.002*	*NS*	*NS*	*0.017*	*NS*	*0.034*

*Some plants died

Additionally, the role of the biology of ficus was prominent through its ability to sprout from hardwood cuttings and reach the heights and the extent of root development observed. Danthu *et al*. (2002) observed previously that ficus can root during propagation with stem and aerial root cuttings compared to twelve other ficus species. It was observed that the ficus roots tracked the concentration of amendments found near the soil surface in the Technosol pots, particularly in the FM and FM+WA treatments. In contrast, deep root penetration was observed in the FS. The ficus roots in the Technosol were also thicker (Fig. 2), formed a turf, clasped to the mineral soil particles of the holding them in place. The results suggest that ficus has a strong rooting system that could be strategically manipulated to stabilize coarse-textured of toxic Technosols through phytostabilization. Higher root biomass and root: shoot ratio in the Technosol at five months suggests that at the early stages of growth, the amount available plant nutrients in the soil was limited causing the plants to optimize nutrient resources by allocating them to the roots. This suggests a struggle by the plants to utilize the limited nutrient resources for survival in the harsh soil conditions (Ågren and Franklin, 2003)

Conclusion: This study revealed the potential of incorporating human excreta and WA as soil amendments and native multipurpose ficus in mine land reclamation. It is proposed that the human excreta and WA be mixed with the Technosols where possible, especially in planting holes before planting to enhance deep root establishment and this should be followed by a second application. Further research under field conditions is required to ascertain these findings in different Technosols, particularly in the long term.

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