

## Full Length Research Paper

# Effects of technosol substrates on soybean growth on Greenhouse experiments in Rwanda

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Accepted 16 May, 2016

Large areas of the Gatumba Mining District (GMD) in Rwanda are covered by Technosols (pegmatite or pegmatite-soil mixtures) resulting from coltan (Colombite and Tantalite) mining activities. These substrates are very poor in total and available plant nutrient contents and are therefore low in soil productivity. Due to agricultural land shortage in Rwanda, almost all the available land is farmed. The present study was conducted to evaluate the effect of different fertilizers on plant nutrient uptake and biomass production of soybean. A greenhouse pot experiment using pegmatite substrate alone and a pegmatite-Lixisol Bt mixture was conducted in a complete randomized design (CRD). *Tithonia diversifolia* biomass (T) was applied at 5 tonnes (t) dry matter (DM) ha<sup>-1</sup> alone and combined with triple superphosphate (TSP), matongo rock phosphate (MRP) and ammonium sulphate (AS). The results demonstrate that soybean DM, grain yield, nitrogen (N), phosphorus (P) and potassium (K) uptake were higher on pegmatite than on the mixture and the combination of T, TSP and MRP (total: 50 kg P ha<sup>-1</sup> with 70% from MRP and 30% from TSP) which gave higher DM yields compared to the other treatments. The integration of tithonia green manure and different inorganic fertilizers significantly increased the N, P and K uptake by soybean above ground and root biomass versus tithonia alone.

**Key words:** Tithonia, soybean, pegmatite, Lixisol Bt, Matongo rock phosphate.

## INTRODUCTION

Rwanda is one of the countries in which coltan has been mined in Africa. Besides Rwanda, the Democratic Republic of Congo, Uganda, Burundi, Ethiopia and Nigeria have exploited coltan for half a century in variable quantities (Zogbi, 2005). In the GMD of Rwanda, pegmatite containing coltan occurs rather frequently

(Dewaele, 2007). Pegmatite is a coarse-grained (usually larger than 2.5 cm in size) intrusive igneous rock composed of mainly quartz, feldspar and mica (mainly muscovite). Coltan mining in the GMD has commonly been practiced in open casts and thus has left behind large areas with degraded land. Due to land shortage and in face of low soil fertility in most parts of the country, Technosols on mine spoils have become under increased use for agricultural production. While “natural” soils used for agriculture commonly have adequate amounts of

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available nitrogen and phosphorus to enable plant production, this is not generally true for mine rock and tailings (Gardiner, 1979). To improve soil productivity in the GMD, local farmers have either covered pegmatite material with substrate from subsoil horizons (for example, Bt material from Lixisols or Bw material from Cambisols) from the margins of casts or have prepared Technosols from pegmatite-subsoil mixtures. However, it is obvious that without any nutrient amendments, these substrates will remain low in productivity. Up to now, there exists almost no knowledge about the effect of the application of deficient nutrients from inorganic and organic sources on crop yields and nutrient uptake in the GMD. In Rwanda, *Tithonia diversifolia* is widely spread along major roads, boundary hedges, and on waste and cultivated lands.

The abundance and adaptability of *T. diversifolia* to various environments coupled with its rapid growth, very high vegetative matter turn-over, more efficient in absorbing nutrients (Liasu et al., 2008) and near nil investment cost on its production makes it a suitable candidate for soil regeneration among smallholder farmers. Soybean (*Glycine max*) was chosen as a test crop since it was one of the representative crops for the Rwandan subsistence agriculture (Verdoodt and Van Ranst, 2003). It is locally grown by GMD farmers due to its relatively high lipid and protein content in its seeds and high nutritional quality (Hoff et al., 1982). Soybean is an N<sub>2</sub>-fixing plant and 50-60% of soybean N demand can be met by biological N<sub>2</sub> fixation (Salvagiotti, 2008).

The objectives of this study are: (1) to compare the effects of two Technosol substrates (pegmatite alone and pegmatite-Lixisol Bt mixture from the GMD) on soybean growth, and (2) to compare the effects of incorporated tithonia leaves and different inorganic fertilizers on biomass production and plant uptake of N, P and K. The results are not only important for recultivation of mining areas in the GMD but also for similar areas in Rwanda and in other African states. The motivation to mix pegmatite with Lixisol Bt material was to increase the water holding capacity which is very important during the dry season, to enhance the potential of SOM accumulation in the longer term (mineral-organic complexes) and to increase the cation exchange capacity (CEC) of the soil substrate. This mixture is already being practiced by farmers in GMD, however, the two substrates were mixed in a well-defined equal ratio (1:1) and the experiment was conducted under controlled conditions in a greenhouse.

## MATERIALS AND METHODS

### Study area

The substrates (pegmatite and Lixisol Bt material) for the greenhouse experiment were collected in the Gisuma catchment, a sub-area of the GMD. The GMD is situated

next to the Nyabarongo River between the longitudes 29°37' and 29°40' E and the latitudes 1°53' and 1°56'. The "natural" soils (soils which have developed outside of the mining areas) of the GMD are representative for the tropical highlands of Rwanda.

### Collection of substrates for the greenhouse experiment

Argic B horizon (Bt) material from a Lixisol next to a mining place and pegmatite material from an open cast mine in the GMD were collected to be used for the greenhouse experiment.

### Establishment of the greenhouse experiment

The substrates collected in the GMD were transported at the National University of Rwanda in Butare where they were air-dried and sieved with a 4 mm sieve. A total of 22 pots (diameter: 24 cm; height: 22 cm) were filled with 5 kg pegmatite material (DM) each. A mixture (1:1) from Lixisol-Bt and pegmatite material was prepared and another 22 pots were filled with 5 kg of the mixture (DM). From the upper 10 cm of each pot, 2 kg of the substrates (DM) were removed and mixed with mineral fertilizers according to the treatments [T1: tithonia 5 t DM ha<sup>-1</sup>, T2: tithonia + TSP (50 kg P ha<sup>-1</sup>), T3: tithonia + MRP + TSP (50 kg P ha<sup>-1</sup> (70% MRP, 30% TSP), T4: Tithonia + MRP (50 kg P ha<sup>-1</sup>) + AS (50 kg N ha<sup>-1</sup>), T5: Tithonia + MRP (50 kg P ha<sup>-1</sup>)]. Tithonia biomass (5 t DM ha<sup>-1</sup> leaves) was incorporated before the substrates were re-filled into the pots. A complete randomized design was used with 3 replicates. Four seeds of soybean were sown at 5 cm depth and only 3 were kept to grow in each pot. The moisture content for the substrates was maintained around 60% of water holding capacity during the entire growing period. The water content was controlled gravimetrically by routinely daily weighing of each pot (Table 1).

### Plant material and soil substrate sampling

Exactly 113 days after seeding, plant parameters were determined including soybean plant height, pod numbers, shoot and root dry matter weight and grain yield. Roots were thoroughly removed from the soil and washed to remove soil particles and dried at 35°C for 48 h before dry weight determination. An aliquot of 500 g soil substrate for subsequent analyses was sampled from each pot after homogenization of the whole volume. The materials were air dried at 25°C and mixed thoroughly.

### Chemical analyses

Substrates of each treatment were analyzed at the onset (Table 1) and at the end (Table 2) of the experiment for pH, total C and N, available P, and exchangeable Ca,

**Table 1.** Chemical properties of *Tithonia diversifolia* leaves, Matongo rock phosphate (MRP), triple super phosphate (TSP) and ammonium sulphate.

Fertilizer type	Fertilizer properties (%)						
	Total C	N	P	K	S	Ca	Mg
Tithonia	40	5.25	0.3	3.22	-	2	0.3
MRP	0.19	0.01	4.8	-	-	-	-
TSP	-	-	20.2	-	-	-	-
Ammonium sulphate	-	21	-	-	24	-	-

**Table 2.** Selected properties of experimental substrates before seeding.

Substrate	Pegmatite	Lixisol Bt	Mixture (1:1)
pH H <sub>2</sub> O	6.3	4.6	5.8
pH KCl	5.1	3.7	3.9
Organic carbon (%)	0.00	0.49	0.2
Total N (%)	0	0.07	0.034
Available P (%)	0.00	0.0015	0.00079
Sand	87.5	32.5	55.5
Silt	4.4	7.4	5.3
Clay	8.1	60.1	39.2

Mg, Na, and K. The analyses were conducted according to standard methods (IITA, 1979). Total N was determined by semi-microkjeldahl digestion and distillation techniques. Available P was extracted with the method of Bray and Kurtz (1945) and subsequently determined colorimetrically. Exchangeable K, Mg, Na and Ca were determined using an atomic absorption spectrophotometer (AAS). Organic carbon was determined using the adapted method of Walkley and Black (1934). The pH was analyzed in deionized water and in 1N KCl using a pH electrode (Rhoades, 1982). Plant samples were analyzed for total P and K using a single Kjeldahl digestion then P was determined by colorimetric method while K was analyzed by AAS. Nitrogen was determined using Kjeldahl digestion and distillation techniques (Okalebo, 2002).

### Statistical analyses

Three homogenized aliquots from the 3 replicates of the same treatment were mixed to make up 1 composite sample for each treatment which was then analyzed. All measurements were replicated three times. Statistical analyses of all data were conducted by two way ANOVA with least significant difference (LSD) using Genstat discovery statistical software package (edition 4).

Treatment means were compared using Duncan's multiple range tests and Fisher's protected least significance difference (LSD) at 95% level of probability (VSN International, 2008).

## RESULTS

Chemical characteristics of the substrates measured before seeding are presented in Table 1. The pH of the pegmatite substrate was slightly acid (6.3), falling into a category preferred by most plants while the pegmatite-Lixisol Bt mixture was more acid (5.8). The mixture contained more N, C, and P compared to the pegmatite substrate. The texture of the pegmatite substrate was loamy sand while the pegmatite-Lixisol Bt mixture was a sandy clay (Table 2).

The chemical characteristics of substrates determined after soybean harvest are presented in Table 3. When compared to the mixture, pegmatite was significantly ( $p < 0.05$ ) higher in pH water, pH<sub>KCl</sub> and available P. Compared to the pegmatite, the mixture was significantly ( $p < 0.05$ ) higher in exchangeable Mg and in total N especially in treatments that received ammonium sulphate fertilizer. However, there was no significant difference ( $p < 0.05$ ) between fertilizer treatments in pH, C, Ca, K, Na and Mg (Table 3).

### Development of soybean during growth period and harvest data

The plants developed quite well during the whole growing season except for the soybeans grown on the mixture which were showing slight nitrogen deficiency symptoms (formation of chloroses) 15 days after seeding, but the chloroses disappeared again 25 days after sowing.

**Table 3.** Effect of green tithonia biomass and mineral fertilizers on soil properties of Gatumba mining district of Rwanda.

Treatment	pH <sub>w</sub>	pH <sub>KCl</sub>	C	N	Av.P	Exchangeable base cations			
						K	Ca	Mg	Na
			%	%	ppm				
<b>Pegmatite</b>									
T	7.3 <sup>b</sup>	7.0 <sup>c</sup>	0.05 <sup>a</sup>	0.015 <sup>a</sup>	1.45 <sup>b</sup>	0.40 <sup>a</sup>	1.54 <sup>a</sup>	0.50 <sup>ab</sup>	0.40 <sup>a</sup>
T+ MRP	7.2 <sup>b</sup>	6.6 <sup>bc</sup>	0.06 <sup>a</sup>	0.013 <sup>a</sup>	2.19 <sup>cd</sup>	0.28 <sup>a</sup>	1.49 <sup>a</sup>	0.50 <sup>ab</sup>	0.43 <sup>a</sup>
T+ TSP	7.0 <sup>b</sup>	6.3 <sup>b</sup>	0.03 <sup>a</sup>	0.016 <sup>a</sup>	1.98 <sup>bc</sup>	0.42 <sup>a</sup>	1.06 <sup>a</sup>	0.4 <sup>a</sup>	0.40 <sup>a</sup>
T+MRP +AS	6.7 <sup>b</sup>	6.4 <sup>bc</sup>	0.25 <sup>b</sup>	0.034 <sup>bc</sup>	2.76 <sup>d</sup>	0.37 <sup>a</sup>	1.60 <sup>a</sup>	0.53 <sup>abc</sup>	0.40 <sup>a</sup>
T+MRP+TSP	7.0 <sup>b</sup>	6.7 <sup>bc</sup>	0.18 <sup>a</sup>	0.024 <sup>ab</sup>	2.60 <sup>d</sup>	0.52 <sup>a</sup>	1.46 <sup>a</sup>	0.46 <sup>a</sup>	0.44 <sup>a</sup>
<b>Mixture</b>									
T	4.9 <sup>a</sup>	4.2 <sup>a</sup>	0.14 <sup>a</sup>	0.025 <sup>ab</sup>	0.22 <sup>a</sup>	0.60 <sup>a</sup>	1.62 <sup>a</sup>	0.77 <sup>bcd</sup>	0.48 <sup>a</sup>
T+MRP	4.9 <sup>a</sup>	4.1 <sup>a</sup>	0.07 <sup>a</sup>	0.055 <sup>d</sup>	0.45 <sup>a</sup>	0.60 <sup>a</sup>	1.31 <sup>a</sup>	1.00 <sup>e</sup>	0.55 <sup>a</sup>
T+TSP	4.8 <sup>a</sup>	4.3 <sup>a</sup>	0.1 <sup>a</sup>	0.048 <sup>cd</sup>	0.68 <sup>a</sup>	0.56 <sup>a</sup>	1.95 <sup>a</sup>	0.80 <sup>cd</sup>	0.44 <sup>a</sup>
T+MRP+AS	4.9 <sup>a</sup>	4.2 <sup>a</sup>	0.04 <sup>a</sup>	0.404 <sup>f</sup>	0.41 <sup>a</sup>	0.64 <sup>b</sup>	1.69 <sup>a</sup>	0.86 <sup>e</sup>	0.54 <sup>a</sup>
T+MRP+TSP	4.9 <sup>cd</sup>	4.1 <sup>cd</sup>	0.22 <sup>d</sup>	0.287 <sup>e</sup>	0.41 <sup>d</sup>	0.25 <sup>cd</sup>	0.89 <sup>cd</sup>	0.54 <sup>uvu</sup>	0.45 <sup>d</sup>

Means with different letter in each single column are significantly different between treatments at ( $P < 0.05$ ) Duncan's test.

Soybean height ranged from 33.81 cm (tithonia) to 49.04 cm (tithonia + MRP + TSP). Shoot DM production followed the order: tithonia + MRP + TSP > tithonia + TSP > tithonia + MRP + AS > tithonia > tithonia + MRP. Mean dry matter ranged from 8.43 g pot<sup>-1</sup> (tithonia + MRP) to 13.3 g pot<sup>-1</sup> (tithonia + MRP + TSP). Root DM production ranged from 1.94 g pot<sup>-1</sup> (tithonia + TSP) to 4.3 g pot<sup>-1</sup> (tithonia + MRP + AS). On the mixture, mean plant height ranged from 27.47 cm (tithonia) to 41.67 cm (tithonia + MRP + TSP) and shoot DM production followed a similar trend ranging from 5.82 g pot<sup>-1</sup> (tithonia) to 9.17 g pot<sup>-1</sup> (tithonia + MRP + TSP). Root DM production ranged from 1.94 g pot<sup>-1</sup> (Tithonia + TSP) to 5.07 g pot<sup>-1</sup> (tithonia + MRP + AS). On pegmatite substrate, soybean grain yield (around 14% water content) followed the order: tithonia + MRP + TSP > tithonia + AS > tithonia + TSP > tithonia > tithonia + MRP, and the mean ranged from 1.674 t ha<sup>-1</sup> (tithonia + MRP) to 2.065 t ha<sup>-1</sup> (tithonia + MRP + TSP). On the pegmatite-Lixisol Bt mixture, soybean grain yield (around 14% water content) followed the order: tithonia + MRP + TSP > tithonia + TSP > tithonia + AS > Tithonia + MRP > tithonia, and the mean soybean grain ranged from 1.59 t ha<sup>-1</sup> (tithonia + MRP + TSP) to 1.04 t ha<sup>-1</sup> (tithonia) (Figure 1).

The number of pods per soybean plant was significantly higher ( $p=0.05$ ) on pegmatite than on the mixture. On both pegmatite and mixture, the highest pod numbers were obtained on the treatment tithonia + TSP + MRP (9.3 pods and 5.7 pods, respectively) and the lowest on tithonia + MRP (5 pods on pegmatite and 4.3 pods on the mixture). Soybean mean number of seeds per plant was higher on pegmatite (11 seeds per plant) than on the mixture (8 seeds per plant). The highest number of

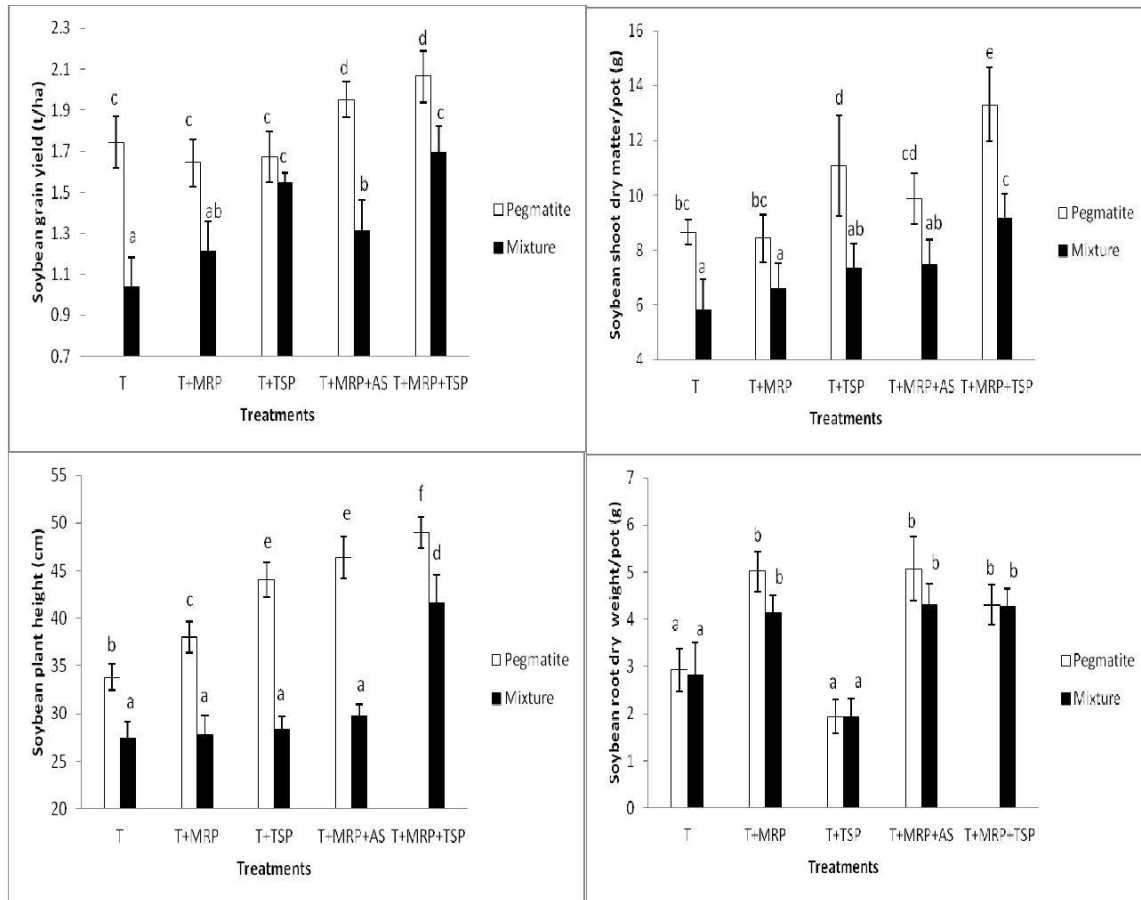
seeds per plant was observed on the treatment tithonia + TSP + MRP (15.3 seeds per plant on pegmatite and 10 seeds per plant on the mixture). The lowest mean number of seeds per plant was found on the treatment tithonia + MRP (8.3 seeds per plant) on pegmatite, and was also found on the treatment that received only tithonia (6.3 seeds per plant) on the mixture (Figure 2).

The above ground soybean biomass uptake of N, P and K were higher on pegmatite than on the substrate mixture (Table 3). The combination of tithonia, MRP and TSP had the highest N, P and K uptake followed by the treatment tithonia + MRP + AS, while the nutrient uptake was lowest in the tithonia + MRP on pegmatite and tithonia on the mixture treatments. The highest N and K storage in roots was observed in the tithonia + MRP + AS treatment and the highest P storage occurred in the tithonia + MRP on pegmatite treatment. For the mixture, the highest root N storage was observed on tithonia + MRP + AS, the highest P and K uptake were on tithonia + MRP and tithonia + MRP + TSP, respectively. In the mixture, the lowest root N and K storage were observed on the tithonia treatment alone while the lowest root P storage occurred on tithonia + TSP (Table 4).

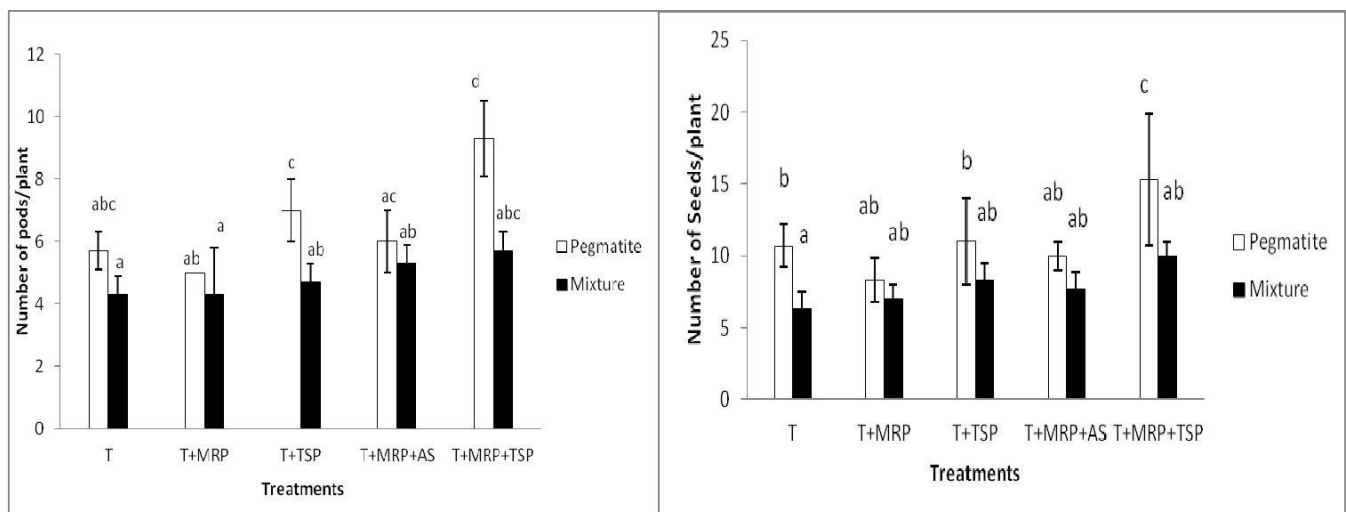
## DISCUSSION

### Soil chemical properties

The pH of both pegmatite slightly increased during the greenhouse experiment and this could have resulted from the release of base cations by the decomposition of tithonia leaves applied which is in agreement with the findings of Shokalu et al. (2010). The higher available P



**Figure 1.** Effects of application of green biomass of tithonia ( $5 \text{ t DM ha}^{-1}$ ) and mineral fertilizers ( $50 \text{ kg P ha}^{-1}$  from MRP, TSP or both; and  $50 \text{ kg N ha}^{-1}$  from AS) on soybean biomass and grain yield for the pegmatite and the pegmatite Lixisol Bt mixture. Data are means of four replicates  $\pm$  S.D. A different letter indicates a significant difference by LSD at the 5% level.



**Figure 2.** Effects of application of green biomass of tithonia ( $5 \text{ t DM ha}^{-1}$ ) and mineral fertilizers ( $50 \text{ kg P ha}^{-1}$  from MRP, TSP or both; and  $50 \text{ kg N ha}^{-1}$  from AS) on soybean number of pods and seeds for the pegmatite and the pegmatite Lixisol Bt mixture. Data are means of four replicates  $\pm$  S.D. A different letter indicates a significant difference by LSD at the 5% level.

**Table 4.** Soybean above ground nutrient uptake and nutrient storage in roots at harvest.

Treatment	Above ground nutrient uptake			Nutrient storage in roots		
	N	P	K	N	P	K
	(kg ha <sup>-1</sup> )			(kg ha <sup>-1</sup> )		
<b>Pegmatite</b>						
T	151.10 <sup>b</sup>	8.48 <sup>e</sup>	78.16 <sup>e</sup>	18.6 <sup>ab</sup>	0.77 <sup>abc</sup>	4.47 <sup>a</sup>
T+MRP	142.19 <sup>b</sup>	7.08 <sup>cd</sup>	64.09 <sup>cd</sup>	20.3 <sup>ab</sup>	1.62 <sup>d</sup>	11.97 <sup>b</sup>
T+TSP	179.29 <sup>c</sup>	10.70 <sup>f</sup>	60.80 <sup>c</sup>	11.9 <sup>a</sup>	0.81 <sup>abc</sup>	3.32 <sup>a</sup>
T+MRP+AS	216.23 <sup>d</sup>	8.46 <sup>e</sup>	60.42 <sup>c</sup>	40.0 <sup>d</sup>	1.16 <sup>c</sup>	12.07 <sup>b</sup>
T+MRP+TSP	225.59 <sup>d</sup>	10.66 <sup>f</sup>	69.46 <sup>d</sup>	30.7 <sup>bcd</sup>	1.10 <sup>c</sup>	11.92 <sup>b</sup>
<b>Mixture</b>						
T	94.28 <sup>a</sup>	4.62 <sup>a</sup>	33.51 <sup>a</sup>	20.2 <sup>ab</sup>	0.52 <sup>ab</sup>	2.42 <sup>a</sup>
T+MRP	135.77 <sup>b</sup>	5.58 <sup>ab</sup>	38.97 <sup>a</sup>	28.4 <sup>bcd</sup>	0.95 <sup>bc</sup>	3.12 <sup>a</sup>
T+TSP	173.72 <sup>c</sup>	7.73 <sup>de</sup>	49.09 <sup>b</sup>	10.7 <sup>a</sup>	0.40 <sup>a</sup>	3.85 <sup>a</sup>
T+MRP+AS	136.11 <sup>b</sup>	6.23 <sup>bc</sup>	51.93 <sup>b</sup>	34.4 <sup>cd</sup>	0.77 <sup>abc</sup>	3.60 <sup>a</sup>
T+MRP+TSP	173.64 <sup>c</sup>	7.63 <sup>ue</sup>	64.67 <sup>uu</sup>	25.9 <sup>uc</sup>	0.84 <sup>auc</sup>	4.03 <sup>a</sup>

Means with different letter in each single column are significantly different between treatments at ( $P < 0.05$ ) Duncan's test.

contents observed in pegmatite compared to the mixture may be explained by the relatively high pH and low contents of components interacting with P such as organic matter, clay and amorphous Fe (Ann et al., 2009). Naidu et al. (1990) explained the increase in P-fixation with decreasing pH through interactions between added P and the soil matrix. The slight increase of soil organic carbon during the growth period in almost all treatments and the yield obtained in the treatment where only tithonia biomass (5 t ha<sup>-1</sup>) was incorporated demonstrates that tithonia may not only be a useful source for plant nutrients but also a source for the formation of soil organic matter (Palm and Rowland, 1999). The higher total N content in the mixture compared to the pegmatite might be partly explained by ammonium fixed in 2:1 clay minerals, as well as the formation of organo-mineral complexes on clay mineral and fine silt surfaces (Nieder et al., 2011).

### Yield of soybean

Soybean root dry weight was higher in pegmatite compared to the mixture and may be explained by the pore size distribution favorable for root growth due to the coarse texture of the pegmatite and its neutral pH that excludes Aluminium toxicity (Roberts et al., 2012). Since an intensive root penetration is important for water and nutrient uptake, the higher root mass on pegmatite may explain the higher grain and shoot dry matter yield compared to the mixture (Grzesiak et al., 2002; Fageria et al., 2006). The combination of tithonia with other P and N fertilizers significantly improved the grain and above ground biomass yields of soybean yield compared to

tithonia alone (Figure 1). The occurrence of higher soybean grain and dry matter yields on pegmatite substrate compared to pegmatite-Lixisol Bt mixture may be partly explained by the lower pH of the mixture which might have caused reduced microbial activity, increased Al availability, and immobilization of phosphate (Reetsch et al., 2007). There was no significant difference in soybean grain yield between the treatment that received tithonia + MRP + TSP and the one that received Tithonia + MRP + AS since P was the main nutrient limiting the growth of soybean. Gardiner (1979) reported that P was the only nutrient which limits the growth of N<sub>2</sub>-fixing legume species on mine rock. Many studies have reported no increase in grain soybean yield when N fertilizers are applied and they assumed that the crop simply substitutes the N it ordinarily would have derived from biological N<sub>2</sub> fixation by N from fertilizer (Deibert et al., 1979; Barker and Sawyer, 2005; Gan et al., 2003; Schmitt et al., 2001). Early application of even small amounts of N often results in temporary suppression of nodule establishment and subsequent activity (Hungria et al., 2005a). Moreover, the high clay content, due to the presence of "high activity clays" in the Bt of Lixisols (Reetsch et al., 2008) might have caused fixation of K<sup>+</sup> and NH<sub>4</sub><sup>+</sup> (Nieder et al., 2011). The relatively higher soybean grain yield observed in pegmatite treated with only tithonia compared to the one treated with tithonia and MRP was probably due to the Ca<sup>2+</sup> released by tithonia during decomposition which may have increased the Ca<sup>2+</sup> concentration in the soil solution above, thereby reducing the rock phosphate solubility through mass action. Karanje et al. (2004) observed a similar reduction of P availability of Mijingu rock phosphate (from Tanzania

after addition of tithonia biomass. Zaharah and Bah (1997) also observed a decrease in the solubility of Algerian rock phosphate following incorporation of green manures.

### Soybean nutrient uptake

The incorporation of tithonia green manure and different inorganic fertilizers significantly increased the N uptake by soybean (above ground and root biomass) compared to tithonia alone (Table 3). The fact that the treatment tithonia + MRP + TSP was the one with the highest N uptake and no significant difference with the treatment that received ammonium sulphate, it shows that soybean could be grown without mineral N fertilizers when N is provided by tithonia green manure and when P is continuously supplied by the combination of the rapid P releasing mineral fertilizer (TSP) and slow P releasing rock phosphate. The highest soybean N uptake on the treatment tithonia + MRP + TSP on all substrates may be an indicator of higher N<sub>2</sub> fixation by soybean when adequate amounts of P are available. Similar results were shown by Basir et al. (2005) and Sarawgi et al. (1999) who found higher N uptake due to supply of P that seemed important for Rhizobium to fix nitrogen, which resulted in increased plant growth and plant N uptake. Lower N uptake on the mixture could also be explained by limitation of N<sub>2</sub> fixation due to soil acidity (Parker and Harris, 1977).

Phosphorus uptake by soybean was higher on pegmatite compared to the mixture due to the low P availability in the mixture which is the effect of its low pH. These conditions might have contributed to aluminium and iron mobilization from aluminium and iron hydr(oxides) and subsequently to the formation of Fe-and Al-phosphates which are stable at low pH (Bolland et al., 2006). The higher P uptake observed from the treatment tithonia + MRP + TSP could be explained by enhanced P availability through blending of low reactive MRP with water-soluble TSP. Application of water-soluble P via TSP might have led to higher P availability through a better root system development (Chien et al., 1987). This technique, with various blending ratios, has shown promising results in many agronomic tests in sub-Saharan Africa (Govere et al., 1995; Van Straaten, 2002; Mnkeni et al., 2000).

The higher K uptake observed on pegmatite compared to the mixture might be partly explained by K fixation due to the high clay content of the mixture. K fixing clay minerals such as illite and montmorillonite are still present in Lixisols (Rowell, 1981; Reetsch et al., 2008). The reduced K uptake on the mixture could also be explained by a slightly progressing compaction of the clay-containing substrate due to periodical watering. This is in accordance with Lipiec (1995) who found the reduction of K uptake by soybean in compacted soil and who mostly

attributed it to the decrease in root surface area. Wolkowski (1990) in his review mentioned that K uptake may be reduced where soil aeration is significantly reduced due to reduction of root respiration. Another reason for the difference in K uptake on the different substrates may be the presence of K-containing muscovite in the pegmatite. On the mixture, higher K uptake was found on the treatment that had higher root and shoot biomass (tithonia + MRP + TSP). This could be due to the higher root density capable of "mining" some of the K that is fixed in the clay interlayers of the mixture (Van Straaten, 2002).

### Conclusions

Technosols in mining areas are very poor in plant nutrients but are generally suitable for reclamation for agricultural use. Tithonia applied with MRP blended with TSP is an effective source of P compared to TSP or MRP alone since it gave the best yield and the highest crop in N, P, and K uptakes. Although N was accumulated in the mixture due to formation of soil organic matter, some of the immobilized N may become available after a state of soil organic matter "equilibrium" is reached. Thus, in the long term, a significant portion of the accumulated N may become plant-available through N mineralization.

### ACKNOWLEDGMENTS

This work was financially supported by Volkswagen foundation (Coltan Project). The authors are grateful to the project partners in the Coltan Project which contributed to the success of this study.

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