REGENERATION, GROWTH AND NUTRIENT PARTITIONING OF THREE WOODY SPECIES ON DEGRADED TROPICAL RAINFOREST LAND

CHOULA, F.[1] – TAFFOUO, V. D.[1*] – PRISO, R. J.[1] – ETAME, J.[1] – ZAPFACK, L.[2] – NTSOMBOH NTSEFONG, G.[2,3] – NGANE, K. B.[4]

[1]*Faculty of Science, University of Douala, B. P. 24157 Douala, Cameroon (e-mail: fchoula@yahoo.fr, dtaffouo@yahoo.com, r_priso@yahoo.fr, etame.jacques@yahoo.fr)*

[2]*The Department of Plant Biology, Faculty of Science, University of Yaounde 1, Cameroon (e-mail: ntsomboh@yahoo.fr, lzapfack@yahoo.fr)*

[3]*Institute of Agricultural Research for Development (IRAD), La Dibamba, B. P. 243 Douala, Cameroon*

[4]*Institute of Agricultural Research for Development (IRAD), Ekona Regional Agricultural Research Center, B. P. 25 Buea, Cameroon (e-mail: nganekoben@yahoo.co.uk)*

**Corresponding author*
e-mail: vtaffouo@yahoo.com; phone: +237 675 90 03 50

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Abstract. Forestry provides the conditions for regeneration of forest species, shortened vegetation succession and duration to reach colonization climax. The impact of inorganic fertilizers [urea (46% N), single superphosphate (33.5% P) and muriate of potash (49.8% K)] single or in combination on growth, regeneration rate and nutrient partitioning in woody species (*Millettia laurentii*, *Microberlinia bisulcata* and *Lophira alata*) was investigated. Some growth parameters [number of leaves (NL), shoot length (SL), stems diameter (SD) and number of branches (NB)], regeneration rate and nutrient uptake (N, P, K, Ca and Mg) were determined. *M. laurentii* and *L. alata* showed higher regeneration rates (82.40 and 84.80% respectively) than those of *M. Bisulcata* (46.40%) 123 DAP. The NL, SL, SD, NB and N, P, K, Ca and Mg uptake in *M. Laurentii* plants were positively influenced by inorganic-N, P, K and NPK fertilizers compared to those of *L. alata* and *M. Bisulcata* 331 DAP. The highest accumulation of N, P, K, Ca and Mg concentrations was found in leaves of all the species. These results suggest that *M. laurentii* could adapt to soil nutrient amendment and can be used as catalyst for reforestation of degraded tropical rainforest land. The specific combination (NPK) was found as efficient fertilizer to enhance the woody species regeneration.
Keywords: *biodiversity, deteriorated soil, forestry, mineral nutrition, restoration*

Introduction

Biodiversity is the occurrence of different types of ecosystems, different species of organisms with the whole range of their variants and genes adapted to different climates, environments along with their interactions and processes (Shmida and Wilson, 1985). According to Dajoz (1985), the ecosystem diversity is due to diversity of niches, trophic levels and ecological processes like nutrient cycling, food webs, energy flow, role of dominant species and various related biotic interactions. Such type of diversity can generate more productive and stable ecosystems or communities able to tolerate various types of stresses such as drought (Bergonzini, 2004). Biodiversity is very

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essential for natural pest control, maintenance of population of various species, pollination by insects and birds, nutrient cycling, conservation and purification of water, and soil formation (Dajoz, 1985). Tropical rain forest is a luxuriant forest composed of broad-leaved trees that form a dense upper canopy and contain a diverse array of vegetation (Gay, 1993). It is found in wet tropical uplands and lowlands around the Equator and usually characterized by a combination of high species diversity, density and productivity (Whitmore, 1984; Choula et al., 2013).

The implementation of development projects such as agriculture, infrastructure construction, mining and forestry exploration leads to land degradation, nutrient load loss and destruction of forest cover (Zapfack et al., 2013; Bonansoa et al., 2016; Ndema Nsombo et al., 2016). These anthropogenic factors are at the beginning of vegetation succession which leads to the creation of a new forest in balance or climax state. One aspect of forest degradation is excavation carried out during the implementation of various projects (i.e. mines and parks) or logging. These areas, once abandoned by man, can be re-colonized by natural succession of vegetation. But for some, there are barriers to the establishment of these successions, such as the insufficient amount of recruitment of vegetative propagules (roots and branches), seeds entering the site, seeds and seedling predation, the absence of a micro-habitat for seed germination and seedling establishment, lack of nutrients in the soil, periodic droughts and competition among herbs (Duncan and Chapman, 1999; Holl, 1999; Guariguata and Ostertag, 2000; Slocum et al., 2004). It has been demonstrated that some successions result in formation of forests in which a particular species is relatively abundant (Bourland et al., 2015). Factors that might influence succession and species diversity include rainfall, temperature and soil chemical properties (Fonge et al., 2011). Succession also depends on the substrate such as on excavated land, sand and lava deposits. The duration of forest succession which takes over a hundred years could be reduced by forestry.

Planting trees is recognized as an effective way to counteract barriers that prevent the vegetation succession process. It changes the physical and biological conditions of the site such as light, temperature and humidity at the soil surface to promote germination; creating shelter to attract wildlife that brings seeds; fertilizes the soil by falling leaves and protects against erosion (Parrota et al., 1997; Aide et al., 2000; Chazdon, 2003). Bailly et al. (1979) describes the forest as the most efficient plant arrangement for the protection of land, with its action exerted through several factors such as the development of the root system that increases soil porosity, the presence of canopies that form an evaporation surface at a certain height, the litter which acts as a sponge that increases retention capacity and promotes the infiltration of water. In addition to the challenges of rapidly restoring forest cover, the choice of planted woody species takes into account several criteria such as the conservation of endangered forest species like *Millettia laurentii* which due to over-exploitation, is currently under conservation measures taken by the state of Cameroon. Despite the fact that it is not in its natural environment, it could adapt to this type of forestry just like a local (*Microberlinia bisulcata*) or pioneer (*Lophira alata*) tree species (Newbery et al., 1998; Lemmens et al., 2008). A variety of soil nutrients must be present in available form for seedlings to be successful. Elements such as carbon, nitrogen (N) and hydrogen usually cycle through the organic material present in the forest, while potassium (K) and phosphorus (P) come from the mineral portion of the soil (Ward and Worthley, 2003). Seedlings also require a variety of minor nutrients such as copper, iron and zinc (Nouck et al., 2016). Moreover, inorganic fertilization can influence soil fertility, regeneration and

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growth of these species on degraded sites in tropical rainforests. Developing soil fertility management options for increased productivity of woody species must be a challenge in most parts of sub-Saharan Africa, where soils are constrained by N and P deficiencies (Abdel-Motagally et al., 2009; Jemo et al., 2010). Adequate supply of inorganic-N fertilizer is beneficial for carbohydrates and protein metabolism, promoting cell division and cell enlargement (Shehu et al., 2010). Similarly, good supply of inorganic-P fertilizer is usually associated with increased root density and proliferation which aid in extensive exploration and supply of nutrients and water to the growing plant parts, resulting in increased growth and yield traits (Maiti and Jana, 1985). Due to the vital role that K plays in plant growth and metabolism, K-deficient plants show a very general phenotype, which is characterized by reduced growth, photosynthesis and impaired osmoregulation and transpiration (Amtmann et al., 2006). Nutrients exported from the soil through harvested biomass or loss from soil by gaseous loss, leaching, or erosion must be replaced with nutrients from external sources. The judicious use of chemical fertilizer is also essential to maintain soil fertility (Hossner and Juo, 1999). There is little knowledge available on the impact of the chemical fertilizers on the growth characteristics and regeneration rate of the woody species on degraded soil of the tropical rainforest for efficient utilization.

Therefore, this study was undertaken to evaluate the impact of inorganic fertilization sources on growth, nutrient uptake and regeneration rate of *M. laurentii*, *M. bisulcata* and *L. alata* plants on degraded tropical rainforest land. We hypothesized that inorganic fertilization sources (N, P and K), single or in combination, can act as efficient fertilizers that will lead to increased plant growth, nutrient uptake and regeneration rate of woody species on degraded tropical rainforest land. A comparative study of the use of these three woody species as catalysts for reforestation in degraded tropical rainforest was also discussed.

Materials and methods

Study area and soil sampling

The SIPO I site located at the South West region of Cameroon covers approximately 30000 km^2 and lies between 9°00′09″ - 9°00′13″E long. and 4°24′40″ - 4°24′45″N lat. (*Fig. 1*). This site was completely cleared of forest cover during oil exploration operations and the soil was excavated about ten meters deep. The climate of SIPO I is characterized by abundant rainfall with average annual rainfall of 3470 mm and average temperature of 26.1 °C. Soils are from sedimentary rocks and are highly acid and eroded (*Fig. 2*, *Table 1*). The horizons of the basement are usually red or yellow, indicating accumulation of free iron oxides. These ultisols are formed on old land surfaces covered by forest vegetation. The physical and chemical characteristics of the soil taken from the excavated land and unaltered land (control sample) are shown in *Table 1*.

Table 1. *Mean values of soil sample constituents from the SIPO I site*

Soil properties	**Experimental site**		**Control**	
	0-30 cm	**30-60 cm**	**0-30 cm**	**30-60 cm**
Particles				
Clay %	20.6d	21.9d	19.0d	18.7d
Limon %	9.3e	10.0e	3.9ef	4.3ef
Sand %	70.1b	68.1b	77.1a	77.0a

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Organic carbon %	0.8g	0.6g	2.4f	1.9f
Total N	0.01i	0.01i	0.3h	0.1h
C/N	80a	60c	80e	19.0d
Available P, mg/kg	14.0de	12.70de	6.5e	5.0e
Al + H (cmol/kg)	4.7ef	4.8ef	1.9f	2.5f
Acidity				
pH (H_2O) 1:2.5	4.5f	4.6f	4.1f	4.1f
pH (KCl) 1:2.5	3.8f	3.8f	3.1f	3.3f
Exchangeable bases (mg/kg)				
Ca^{2+}	4.2f	5.1f	2.9f	4.2f
Mg^{2+}	3.2f	3.1f	3.0f	3.1f
K^{+}	0.2h	0.2h	0.2h	0.1h
Na^{+}	0.1h	0.1h	0.1h	0h
Total bases	7.7e	8.5e	6.2e	7.4e
CEC	7.8e	6.9e	15.4d	11.7de

Data represent mean±SD (n = 5); within rows, means followed by the same letter are not significantly different (p <0.05) by Fisher LSD test. CEC: Cation Exchange Capacity

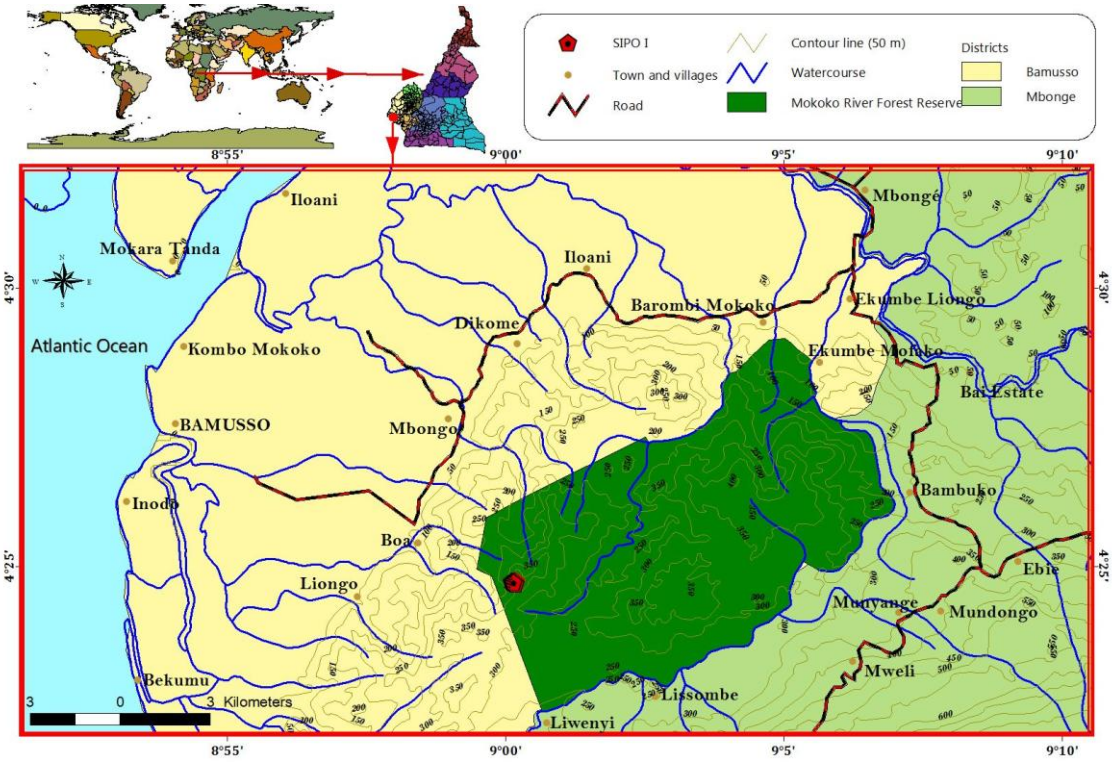

Figure 1. *Location of the SIPO I site in the Mokoko River forest reserve*

Plant material

Millettia laurentii De Wild is a leguminous tree from Africa and native to the Democratic Republic of Congo, Cameroon, Gabon and Equatorial Guinea. It is listed as endangered in the International Union for Conservation of Nature (IUCN) Red List, principally due to destruction of its habitat and over-exploitation for timber. *Microberlinia bisulcata* A. Chev. is also a leguminous species found only in southwestern Cameroon and its natural habitat is subtropical or tropical dry

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forests (Cheek and Cable, 2000). It is also listed as endangered in the IUCN Red List of Threatened Species. This valuable timber species occurs in lowland rainforest areas, usualy on sandy soils in flat areas. Large-scale habitat decline due to clearance for agriculture and exploitation have caused population declines. *Lophira alata* Banks ex Gaertn. is a species of plant in the Ochnaceae family. Its natural habitat is tropical moist lowland forests. The timber is extremely hard and used for railroad ties, electric fences and bridge planking. *L. Alata* needs full sunlight to grow, seedlings can persist for some time in the shady undergrowth and resume growth if breaks in the canopy occur (Biwolé et al., 2012). The seeds of *M. Laurentii* were collected from Mvengue and Mvangan in South Cameroon while those of *L. alata* were originating from the South Bakundo forest. The seedlings of *M. bisulcata* were harvested in the nearby forest.

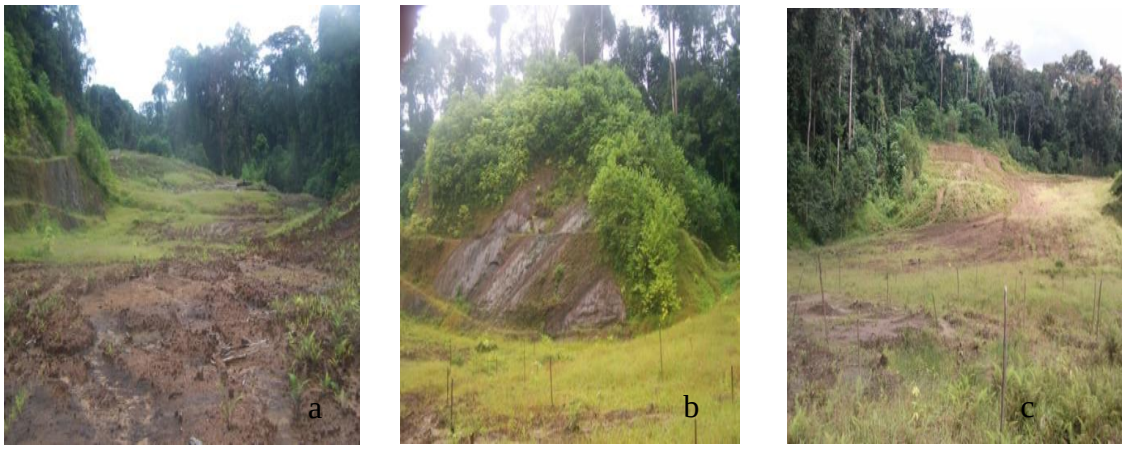

Figure 2. *View of SIPO I showing traces of erosion on the cleared area (a), cleared/ excavated hill (b) and platform (c)*

Methods

Experimental design

The experiment was performed in a randomized complete block design with six replicates. Three fertilizer applications (urea, single superphosphate and muriate of potash) were used on plots each measuring 30 x 30 m. A plot with no fertilizer additions was taken as control. Thirty plots were established to cover the entire area. Each plot consisted of 5 plant rows and 5 columns spaced 4 x 4 m. Each plant was identified with a code (*Fig. 3*) consisting of the name of the plot, the line number and column number. One of the three species was planted on the first three columns of each plot and all three species were planted on the last two. The different fertilizers selected for the experiment were applied in each case around the plant (3 g/plant) 123 days after planting (DAP). Inorganic-N fertilizer was applied as urea (46% N), Inorganic-P as single superphosphate (33.5% P) and Inorganic-K as muriate of potash (49.8% K), singly or in combination (Wamba et al., 2012).

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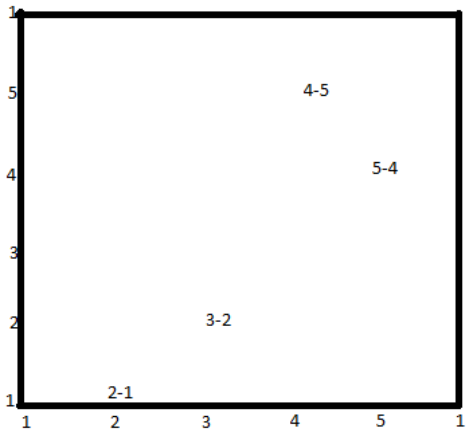

Figure 3. *Codification of plants on the experimental plots.*

Field and laboratory data collection

Stem diameter (SD), shoot length (SL), number of leaves (NL) and number of branches (NB) were recorded at 123, and 331 DAP. Leaves, stems and roots were separately dried at 62 °C for 72 h and their dry weights determined (Taffouo et al., 2010). Leaf Powders were analyzed for total phosphorus (P), total nitrogen (N), calcium (Ca), potassium (K) and magnesium (Mg) in laboratory according to the methods described by Taffouo et al. (2010).

Regeneration rate of plants

The regeneration rate (μ) of plants was calculated as in the following equation:

$$\mu = NL/NT \times 100 \qquad \text{(Eq. 1)}$$

where NL represents the number of live plants and NT the total number of plants in plots.

Soil analysis

Five composite samples prepared from 0-30 and 30-60 cm depths within plots were analyzed in the laboratory of the Institute of Agricultural Research for Development (IRAD), Cameroon. The parameters analyzed included (i) particle size distribution by the method of Davidson (1955), (ii) organic carbon measured by the procedure of Walkley and Black (1934), (iii) exchangeable Ca and Mg of the soil using the procedure of Jackson (1958), (iv) total N content by the method of Kjeldahl (AOAC, 1980), (v) available P by the method of proportioning colorimetric starting from the nitrochlorhydric solution of ashes (Stuffins, 1967), (vi) soil pH measured by the procedure of Nanganoa et al. (2013), and (vii) K content determined using flame photometer (Jenway) (Prevel et al., 1984).

Statistical analyses

All data were statistically analyzed using Statistica (version 9, Tulsa, OK, USA). They were first subjected to analyses of variance (ANOVA). Statistical differences between treatment means were established using the Fisher LSD test at $p<0.05$. Two-

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way ANOVA was used to estimate whether species, nutrient fertilization sources, singly or in interaction had a significant influence on the measured parameters.

Results

Regeneration of seedlings

The regeneration rate of seedlings was estimated by evaluating the number of live plants 123 and 331 days after planting (DAP) (*Figs. 4 and 5*). A significant difference between species was observed for the behavior of seedlings 123 DAP (*Fig. 4*). *M. laurentii* and *L. alata* showed significantly ($p<0.05$) higher number of live plants (82.40 and 84.80% respectively) than those of *M. Bisulcata* (46.40%).

Figure 4. *Number of live plants 123 days after planting (M_b : Microberlinia bisulcata A. Chev. ; L_a : Lophira alata Banks ex Gaertn. ; M_l : Millettia laurentii De Wild). The letters (a, b) indicate significant differences between plant species using Fisher test ($p< 0.05$).*

Under field conditions, inorganic-N, P or K fertilizer sources supplied singly or in combination had significant effects on regeneration rate (*Fig. 5*). Application of N, P or K fertilizers in combination led to a significant ($p<0.05$) increase of number of live plants in all woody species compared to untreated plants (*Fig. 5A, B and C*). Number of live plants was negatively affected by P supply in all plant species (*Fig. 5A, B and C*). *M. bisulcata* had relatively higher number of live plants under NPK fertilization than *L. alata* and *M. laurentii* as compared to the plants fed with K, N or P singly and untreated controls (*Fig. 5A, B and C*). However, *L. alata* and *M. laurentii* showed higher number of live plants than *M. bisulcata* when plants were enriched only with N fertilizer (*Fig. 5A, B and C*).

Growth characteristics

Plant growth was estimated by measuring the stem diameter (SD), shoot length (SL), number of leaves (NL) and branches (NB) 331 DAP (*Table 2*). This study showed a significant increase ($p<0.05$) of SD, SL and NL in *M. laurentii* under inorganic fertilizer application compared to untreated control (*Table 2*). No significant differences were noted for SD, SL and NL in *L. alata* and *M. bisulcata* when inorganic-N, P or K fertilizers was applied singly or in combination, but only N fertilization had a negative influence in SL and NL of *M. bisulcata* (*Table 2*). N, P or K fertilizers applied singly

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and in combination did not influence NB in *M. bisulcata* and *M. laurentii* plants except for K fertilizer with a significant decrease observed compared to untreated plants (*Table 2*). A significant two-way interaction between the factors 'nutrient fertilization sources' and species was observed for SL and NL (*Table 2*). In *M. laurentii*, the plants supplied with N, P or K fertilizers singly or in combination showed significantly ($p<0.05$) higher SD, SL, NL and NB compared to *L. alata* and *M. bisulcata* plants 331DAP (*Table 2*).

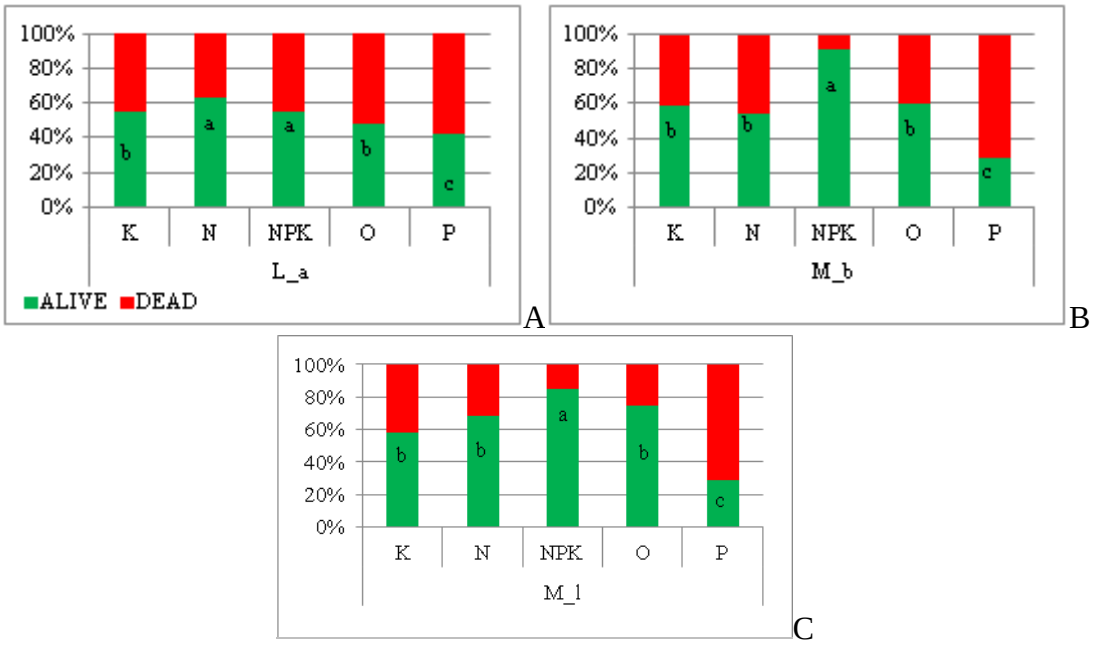

Figure 5. *Number of live and dead plants (%) 331days after planting under different fertilizer treatments. A : L_a : Lophira alata Banks ex Gaertn. ; B : M_b : Microberlinia bisulcata A. Chev. ; C : M_l : Millettia laurentii De Wild N : N 46% ; K : K_2O 49.8% ; NPK : NPK 20- 10- 10 % ; P : P_2O_5 33.5% and O : Control treatment. The letters (a, b) indicate significant differences between treatments using Fisher test ($p < 0.05$).*

Nutrient partitioning

The nutrient contents in leaves, stems and roots of *L. Alata, M. bisulcata and M. laurentii* were affected by different inorganic fertilizer sources (*Table 3*). Application of inorganic-N, P or K fertilizers singly or in combination had a positive effect on leaf N concentrations in all three woody species (*Table 3*). Leaf K content was positively influenced by different inorganic fertilizer sources in *M. Laurentii* (*Table 3*). *M. Laurentii* plants supplied with N, P, and NPK fertilizers showed significantly ($p<0.05$) higher leaf N, P, Ca and K concentrations, respectively than those of *L. Alata and M. bisulcata*. Application of inorganic-N, P or K fertilizers singly or in combination on the contrary, decreased leaf Mg concentration in *L. Alata*, stem N concentration in *M. Bisulcata* and root Ca concentrations in *M. Laurentii* plants (*Table 3*). Application of inorganic-P fertilizer enhanced leaf Mg concentration significantly ($p<0.05$) in *M. Laurentii* plants compared to untreated control (*Table 3*). Under inorganic fertilizer application, the leaves of all three species showed significantly ($p<0.05$) higher amount of N, P, K, Ca and Mg than those of stems and roots except for stem Ca and Mg in *L.*

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Alata plants. A significant two-way interaction between the factors 'species' and 'inorganic fertilizer sources' was observed for N and Mg concentrations (*Table 3*).

Table 2. *Mean values of growth parameters in woody species at the vegetative stage (331 DAP) under inorganic fertilizer applications*

Species	Inorganic fertilizer (g/plant)	Plant growth parameters			
		Stem diameter (mm)	Shoot length (cm)	No. of Leaves	No. of branches
L. alata	control	4.29±1.16c	22.07±3.15f	5.43±0.80e	-
	NPK	5.31±0.98c	21.00±2.55f	7.19±0.91d	-
	N	4.50±0.91c	21.29±3.26f	5.50±0.50e	-
	P	4.25±1.16c	19.50±5.32f	4.25±0.42e	-
	K	4.10±0.83c	18.00±3.85f	4.30±0.68e	-
M. bisulcata	control	10.63±2.62a	43.67±3.00d	8.87±1.11d	2.33±0.47b
	NPK	7.14±1.67b	45.76±3.46d	6.82±0.37de	2.00±0.00b
	N	8.18±1.89ab	36.00±5.26e	4.86±0.12e	2.00±0.00b
	P	10.57±3.89a	53.05±3.41c	9.89±1.40d	-
	K	9.07±2.05a	49.57±2.05c	8.43±1.96d	1.00±0.00c
M. laurentii	control	7.38±1.50b	44.23±2.28d	15.85±1.77c	3.67±0.93a
	NPK	8.93±2.43ab	71.86±7.30a	19.36±1.95b	3.67±0.63a
	N	9.17±1.71a	60.74±6.31b	21.39±1.96a	4.04±0.16a
	P	9.85±2.93a	74,85±8.64a	18.23±1.54b	2.92±0.54ab
	K	9.29±3.77a	71,86±7.86a	18.86±1.59b	2.29±0.45b
Two-way ANOVA results					
Species (S)		**	**	**	ns
Fertilization sources (F)		*	*	*	ns
Interactions S X F		ns	*	*	ns

Data represent mean±SD (n =12); within columns, means followed by the same letter are not significantly different ($p<0.05$) by Fisher LSD test. The result of the two-way ANOVA analysis showing effects of inorganic fertilizer sources, species, and their interaction (S×F) on the different plant growth parameters. ns not significant, *Significant at $p<0.05$, **Significant at $p<0.01$

Table 3. *N, P, Ca, K and Mg partitioning (mg/plant) of woody species grown under inorganic fertilization sources*

Species		Inorganic fertilization (g/plant)	N	P	Ca	K	Mg
L. alata	Leaf	Control	13.3±0.5c	1.6±0.4b	9.0±0.2d	10.6±0.1bc	9.7±0.4b
		NPK	13.9±0.2c	1.5±0.5b	4.4±0.1f	9.3±0.2bc	1.5±0.2c
		N	19.0±1.2b	1.9±0.2b	5.4±0.1ef	11.0±0.3b	2.8±0.2c
		P	12.7±1.0c	1.5±0.2b	4.9±0.1ef	7.4±0.2c	3.2±0.2c
		K	19.0±1.4b	1.9±0.4b	4.6±0.1f	8.5±0.2c	1.3±0.3c
	Stem	Control	3.0±0.2e	0.6±0.0cd	3.4±0.4f	5.5±0.4cd	1.1±0.0c
		NPK	3.6±0.2e	0.4±0.0de	13.2±0.2c	3.2±0.1d	12.5±1.1a
		N	3.0±0.1e	0.9±0.1c	9.4±0.3d	8.2±0.7c	11.4±1.2a
		P	2.3±0.1ef	1.0±0.2c	17.3±1.7b	1.9±0.1e	9.7±1.1b
		K	9.0±0.1d	1.4±0.1bc	13.4±1.3c	4.7±0.1d	11.8±1.2a
	Root	Control	4.0±0.1e	0.3±0.0de	12.5±0.4c	2.1±0.2g	2.3±0.2c
		NPK	2.7±0.2ef	0.2±0.0e	4.2±0.1f	6.6±0.5c	1.4±0.4c
		N	4.0±0.4e	0.3±0.0de	6.2±0.3e	6.8±0.6c	1.3±0.2c
		P	2.7±0.1ef	0.4±0.0de	10.5±0.7c	6.7±0.5c	1.9±0.8c
		K	5.6±0.5de	1.0±0.1c	8.9±0.5de	6.1±0.6c	1.8±0.1c

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Species		Inorganic fertilization (g/plant)	N	P	Ca	K	Mg
M. bisulcata	Leaf	Control	1.7±0.1f	0.3±0.0de	10.4±0.1c	6.4±0.1c	2.6±0.1c
		NPK	5.9±0.2de	0.5±0.0d	8.1±0.5de	5.6±0.9cd	2.0±01c
		N	7.3±0.7d	0.7±0.0cd	1.3±0.8g	6.5±0.1c	3.3±0.1c
		P	4.2±0.6e	1.2±0.2c	16.9±2.1b	5.7±0.2cd	0.2±0.0f
		K	5.1±0.3de	0.8±0.1c	11.4±0.9c	4.4±0.1d	1.3±0.0c
	Stem	Control	5.6±0.2de	1.0±0.0c	2.3±0.2fg	3.8±0.1d	1.3±0.0c
		NPK	0.8±0.1f	1.9±0.1b	5.9±0.3ef	8.1±0.5c	2.1±0.1c
		N	1.1±0.1f	1.2±0.3c	3.7±0.7f	5.6±0.1cd	1.0±0.0c
		P	0.7±0.0f	1.4±0.1bc	4.4±0.3f	6.6±0.2c	1.4±0.1c
		K	2.2±0.1ef	1.6±0.1b	4.0±0.7f	6.7±0.3c	1.2±0.1c
	Root	Control	3.8±0.5e	0.8±0.1c	3.4±0.5f	3.5±0.7d	1.3±0.1c
		NPK	7.0±0.6d	0.6±0.1cd	7.4±0.5e	4.1±0.1d	1.5±0.3c
		N	3.9±0.2e	0.3±0.0de	3.1±0.3f	4.4±0.3d	1.6±07c
		P	5.7±0.2de	0.7±0.1cd	2.8±0.4f	4.2±0.1d	1.3±0.4c
		K	11.3±1.2c	0.7±0.1cd	2.6±0.5f	4.9±0.2d	1.1±0.3c
M. laurentii	Leaf	Control	14.0±1.8c	1.2±0.1c	11.7±0.6c	13.8±0.2b	2.3±0.4c
		NPK	20.6±1.2b	1.4±0.0bc	18.4±0.4a	17.1±0.3a	3.8±0.8c
		N	26.6±0.8a	1.7±0.1b	10.2±0.5c	16.3±0.6a	2.9±0.5c
		P	24.8±0.7a	2.9±0.1a	16.0±0.7ab	15.9±0.6a	8.9±0.9b
		K	26.8±1.9a	1.5±0.0c	12.9±0.2c	16.0±0.7a	3.2±0.5c
	Stem	Control	1.0±0.0g	0.5±0.0d	15.2±0.4b	6.6±0.1c	1.9±0.1c
		NPK	11.5±0.2c	0.6±0.1d	14.6±0.6bc	11.0±0.6b	1.9±0.1c
		N	6.2±0.2d	0.3±0.0de	15.4±0.7b	11.3±0.5b	2.7±0.0c
		P	7.1±0.3e	0.3±0.0de	17.5±0.8a	13.5±0.4b	2.3±0.0c
		K	10.1±0.1cd	0.9±0.1c	17.6±0.9a	9.1±0.6bc	2.6±0.1c
	Root	Control	1.5±0.3f	0.3±0.0de	13.5±0.5c	5.0±0.1cd	1.1±0.0c
		NPK	1.4±0.1f	0.3±0.0de	6.3±0.5d	7.8±0.3c	1.9±0.0c
		N	1.4±0.1f	0.2±0.0e	8.5±0.4cd	6.5±0.1c	2.3±0.1c
		P	3.2±0.3e	0.2±0.0e	5.6±0.4e	4.0±0.2d	0.7±0.0d
		K	1.5±0.0f	0.4±0.0de	7.8±0.7d	5.5±0.2cd	1.9±0.1c
Two way ANOVA results							
Species (S)			*	ns	*	ns	*
Fertilization sources (F)			**	ns	*	ns	*
Interaction S x F			*	ns	ns	ns	*

Data represent mean±SD (n = 5); within columns, means followed by the same letter are not significantly different ($p<0.05$) by Fisher LSD test. The result of the two-way ANOVA analysis showing effects of species, soil nutrient fertilization, and their interaction (S x F) on plant nutrient status ns not significant,*significant at $p<0.05$, **significant at $p<0.01$

Discussion

The restoration of degraded land in the SIPO I site of Boa forest can be catalyzed by forestry techniques which in addition, provide the conditions for regeneration of forest species, shortened vegetation succession and duration to reach colonization climax (Dajoz, 1985). *M. laurentii* and *L. alata* showed higher number of live plants than those of *M. Bisulcata* 123 DAP. These results suggested the adaptation of *M. laurentii* and *L. alata* to distinct combinations of light, moisture, and soil amendments of SIPO I site. Similar results were also observed by Ward and Worthley (2003). The lower performance presented by *M. Bisulcata* at this vegetative stage (123 DAP) compared to those of pioneer species (*M. laurentii* and *L. Alata*) could be

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explained by some limiting factors: (1) top soils of forests are covered with litter which endows them with particular nutritive characteristics (Ibrahim et al., 2010); (2) degraded zones lost some soil characteristics during implementation of industrial and mining projects. In fact, in the SIPO I site where excavation was done, the structure ranges from sandy loam to loamy-sandy-clay with low values of CEC and total N at all depths, rendering it vulnerable to erosion. Erosion is accentuated by aggressiveness of rainfall on naked land (Roose and Sarrailh, 1990; Graf et al., 2003). The carbon content, total N and CEC are low compared to reference soil and values obtained by Taffouo et al. (2010), Sharma and Raghubanshi (2011), Wamba et al. (2012) and Fokom et al. (2013). The low mineral content of this soil is due to degradation of forest cover (Bonansea et al., 2016; Ndema Nsombo et al., 2016) and the top soil horizons which were absent after excavation (Duryea, 2000). On the contrary, *M. bisulcata* had relatively higher number of live plants under inorganic-NPK fertilizer than *L. alata* and *M. laurentii* as compared to the plants fed with K, N or P fertilizers singly or in combination 331 DAP. Ouédraogo et al. (2014) and Fayolle et al. (2015), studying the regeneration of a pioneer species (*Milicia excelsa*) and a non-pioneer species (*Pericopsis elata*) found that a pioneer species presented significantly lower performance than a non-pioneer species when planted on forest clearings. These results could be explained by the fact that pioneer species might not require optimum environmental conditions to thrive. According to Duryea (2000), the main root of these plants was reduced during planting to avoid folding of the root system in the form of "L" or "J" which is one of the drawbacks of using seedlings for regeneration. Efficient sylvicultural operations on such soil requires selection of plant species that are capable of adapting to it. Otherwise, it is important to consider modification of the site's soil structure and fertility (Lamd, 1994; Ndema Nsombo et al., 2010).

Soil nutrients play a role in the life cycle of the tree and must be present for survival and successful growth. In short supply, one or more nutrients can be the limiting factor to the growth and development of trees or stands (Ward and Worthley, 2003). In the present study, application of inorganic-N, P or K singly or in combination led to a significant increase in SL, SD, NL and NB in *M. laurentii* plants. Adequate supply of inorganic-N is beneficial for carbohydrates and protein metabolism, promoting cell division and cell enlargement (Shehu et al., 2010; Debere et al., 2014). Similarly, good supply of inorganic-P is usually associated with increased root density, soil porosity and proliferation which aid in extensive exploration and supply of nutrients and water to the growing plant parts, resulting in increased growth and yield traits (Bailly et al., 1979; Maiti and Jana, 1985). Due to the vital role that K plays in plant growth and metabolism, K-deficient plants show a very general phenotype, which is characterized by reduced growth, photosynthesis and impaired osmoregulation and transpiration (Amtmann et al., 2006). In this study, no significant differences were noted for SD, SL and NL in *L. alata* and *M. bisulcata* when inorganic-N, P or K was applied singly or in combination. The minimum amount of light required for optimum growth and development varies dramatically among tree species. According to Ward and Worthley (2003), species that compete best in full sunlight have the capacity for rapid height growth and are often found in the upper layers of the forest canopy while those that are capable to compete in the shade of other trees can occupy lower layers in the canopy, and each canopy layer will intercept additional sunlight. In *M. laurentii*, the plants supplied with inorganic-N, P or K fertilizers singly or in combination showed higher SD, SL, NL and NB compared to *L. alata* and *M. bisulcata* 331 DAP. Similar results

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have previously been documented by Ashton et al. (2001) who studied the rain forest in SouthWest Sri Lanka and suggested that the early formation of the branches and the large number of leaves allow trees (catalysts) to cover the site and to create a favorable microclimate for the growth of other forest species. The branches and leaves falling constitute litter which is important for the formation of the humus layer and prevention against erosion (Ibrahim et al., 2010).

The results of this study highlighted the importance of nutrients uptake and their distribution in plant parts of the three woody species. Application of inorganic-N, P or K fertilizers singly or in combination had a positive effect on leaf N concentrations in all the three woody species. Mineral uptake is largely influenced by the availability of soil mineral nutrients which in turn affects the chemical composition of the plants (Juma and Van Averbeke, 2005). Taffouo et al. (2014) reported that N is directly transferred from the roots towards the leaves of plants where the N compounds are used for protein biosynthesis. In this study, *M. Laurentii* (N fixing species) plants supplied with inorganic-N, P or K fertilizers singly or in combination showed higher leaf N, P, Ca and K concentrations than those of *L. Alata and M. bisulcata*. Ojiem et al. (2000) demonstrated that legumes have the potential to improve soil nutrients status through biological N fixation and incorporation of biomass into the soil as green manure. In cowpea, the N requirements for developing pods are not only covered by root uptake or biological N fixation, but also by mobilization of N in vegetative tissues (Douglas and Weaver, 1993). Some food and fodder legumes are known for N fixing ability; however their establishment with P fertilization enhances nodulation and hence fixation of atmospheric N (Masinde and Omolo, 2007). According to Jemo et al. (2010) and Taffouo et al. (2014), the process of foliar N mobilization is dependent on the amount of P uptake by plants. Under inorganic fertilization, the leaves of all the three woody species showed higher amounts of N, P, K, Ca and Mg than those of stems and roots except for stem Ca and Mg in *L. Alata* plants. According to Amtmann et al. (2006), leaves are important to plants and trees because they convert sunlight energy to food through the process of photosynthesis. In this study, the highest accumulation of nutrients was recorded in *M. Laurentii*. In fact this species has been successfully tested for forestry by macro-cuttings (Nsielolo Kitoko et al., 2015). In the analysis combining regeneration rate, growth and nutrient partitioning of the parameters measured, the results revealed the best adaptation by *M. laurentii* to soil nutrient amendment. This species could be used as a catalyst for reforestation in degraded tropical rainforest land.

Conclusions

Restoration of degraded tropical rainforest land in the SIPO I site can be catalyzed by intervention of forestry and agronomic management techniques which provide the conditions for regeneration of forest species, shortened vegetation succession and duration to reach a state of balance of the forest (climax). *M. laurentii* and *L. alata* showed higher number of live plants (82.40 and 84.80% respectively) than those of *M. Bisulcata* (46.40%) 123 DAP. The specific combination (NPK) was found as efficient fertilizer to enhance the woody species regeneration. The highest accumulation of N, P, K, Ca and Mg concentrations was found in leaves compared to stems and roots of all the species.

In *M. Laurentii* plants, SD, SL, NL, NB and N, P, Ca and K uptake were positively influenced by inorganic-N, P, K or NPK fertilizer treatments compared to *L. alata* and *M. Bisulcata* 331 DAP. These results revealed the best adaptation by *M. laurentii* to soil

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nutrient amendment. Therefore, this woody species can be considered as catalyst for reforestation of degraded tropical rainforest land such as that encountered in the SIPO I site of Boa forest in Cameroon.

Based on these attributes *M. laurentii* which is subjected to over-exploitation is strongly recommend for reforestation in degraded tropical rainforest land.

Developing soil fertility management options for increasing productivity of woody species must be a challenge in most parts of sub-Saharan Africa, where soils are constrained by N and P deficiencies.

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