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Evaluation of forest litter mineralization capacity on the growth of *Irvingia gabonensis* in Ogwashi-Uku Forest Reserve, Delta State, Nigeria

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The study evaluated litter production capacity of three forest plantation foliage litters as potential mineralization sources for the growth of *Irvingiaga bonensis*. Litter production capacity of Bamboo, Teak and Gmelina forest plantations was monitored for 70 days before *Irvingia* seeds were sown in open germination beds containing litters soil samples for vegetative development assessment. Data collected were analyzed using ANOVA and significant means separated with the DMRT. Results showed the mean litter production as Teak (3.65t/ha) >Gmelina (3.60t/ha)> Bamboo (2.67t/ha) and germination percentage was highest for soils of Bamboo plantation. The carbon nitrogen ratio was Gmelina (2.60)> Teak (2.24)> Bamboo (1.90) and bulk density as Gmelina (1.59 g/cm^3) > Teak (1.47 g/cm^3) > Bamboo (1.45 g/cm^3). The plant height, leaf area and leaf to stem ratio were Bamboo >Gmelina> Teak while the collar diameter was highest in Teak forest plantation soils. The study showed soils under the Bamboo forest as the best growth media for *I.* gabonensis, and therefore implied soils under the Bamboo forest as potential natural nursery and forest regeneration materials, especially in the current global deforestation menace that have adversely limited the preponderance of silvical floor litters.

Key words: Soil organic matter, litter production, forest soils, decomposition, vegetative development.

INTRODUCTION

The litter component of forest floor is a major soil structural biota that has strong influence on the nutrient composition characteristics in distinguishing forest soils. This is due to the vital biogeochemical role often demonstrated in the mechanistic transformation of key plant elements in forest floor litters to the soil nutrients (Bassey and Opara, 2015; Krishna and Mohan, 2017).

The resultant soil characteristics are significantly determined by the litter component of the forest floors after decomposition by soil fungi, bacteria and other detritivores (Ibanga, 2006; Read and Lawrence, 2003) interact with the litters to produce organic matters as essential nutrient anchorage for soil micro-organisms to efficiently initiate the decomposition and mineralization processes that confers on the forest ecosystems spatial productive functions (Johnson and Cartley, 2002; Six et al., 2004; Noguez et al., 2008; Liu et al., 2010) that regulate the soil properties of given forest type and

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microbial biomass activity. Dechaine et al. (2005) however reported that the physico-chemical environment, litter quality and the composition of the decomposer community regulate litter decomposition rate. More significantly, the leaf litters in forest stands moderate the soil temperature which eventually lowers the oxidation rate of soil organic carbon as well as the transpiration rate, subsequently assisting the bioactivity of the soil micro-organisms which require a wide range of moisture to effectively mineralize into nutrients.

It is on this premise that forests with high species diversity of notably dense leafy canopies represent a variegated source of litter production which may ultimately influence the soil microbial community. Such organic matters varies with tree species (Klein and Dutrow, 2000) and the capacity of the different parts, especially the leaves to photosynthesize in order to create nutrient pools that could become mined by the soil mineralization under favorable environmental conditions. Wu et al. (2012) suggested that the volume of litter falls varies with the composition of the mixed forest, the stand density and anthropogenic activity (Egwunatum et al., 2015),implying that significant differences could occur in the litter quality of a forest stand as nutrient source for the soil under the mixed forest. This therefore underscores the current rate of deforestation as a result of anthropogenic activities (Brunetet al., 2010; Morris, 2010), as a threat to the nutrient pool of the forest soils due to the loss of its preponderant silvical litters for its sustainable enrichment owing to changes in microhabitats and loss of forest biodiversity (Bengtsson et al., 2000; Chaudhary et al., 2016). Brady and Weil (2002) reported that plants on tropical soils recycles approximately 60-80% of minerals, with calcium and phosphorus attaining more than 99% from the soil by the roots of forest trees. This also implies that in addition to the litter concept in the enhancing the forest soil, the root biome plays significant role in the uptake of nutrient from restricted locations in the soil (Speengeren, 2005). Thus to a large extent, especially in the evergreen and secondary forests where there is relatively low leaf shedding and high exploitations respectively, the roots represent potent litter capacity framework for enriching the forest soil. It is these interplay that eventually modify and enrich the forest soil which overtime endangers it as potential fertile soil for agriculture. This therefore confers a significant role on the forest floor as potential input-output system for nutrient regulation via the regular reception of litters at various rates that decompose and mineralize to form edaphic nutrient bridges in forest ecosystems.

Unfortunately, the increasing rate of deforestation particularly for lumbering and collection of minor forest produce has often led to the decline of these forest floor inputs with a commensurate decline in soil nutrient build up in the forest ecosystem. It is against this backdrop that the study was conducted to examine the current level of litter fall and its commensurate nutrient supply to the underlying forest soil under *Tectona grandis*, *Gmelina arborea* and *Bamboo bambusa* forest plantations, as index for choice of soils and site in the growth performance of *Irvingia gabonensis* in the degraded Ogwashi-Uku Forest Reserve.

MATERIALS AND METHODS

Description of study area

The experiment was conducted in the permanent nursery site of the Delta State Ministry of Environment Area field office, beside the Iyi-Ada stream, in the Ogwashi-Uku Forest Reserve. It is located on latitude 6° 25' N and longitude15° 25'E in the lowland rainforest ecological zone of Delta State. The mean temperature is 28°C and annual rainfall averages 1800mm that peaks in July-September (NiMet, 2016). The vegetation is mostly secondary forest of over 10 ha of *T. grandis* and *G. arborea* with naturally occurring *Bambusa* parchments of over 10 ha. The *T. grandis* and *G. arborea* plantations were last regenerated in the year 2002 (MOE, 2015). The topography of the site is undulating with the teak and bamboo vegetation at the top and valley, respectively. The *G. arborea* stand is sandwiched between the *T. grand is* and Bamboo, with Bamboo vegetation closest to the Iyi-Ada stream in the forest reserve. This natural occurring Bamboo vegetation has significantly assisted in abating the observed erosion that is on the increase following the massive deforestation without regeneration as seen on the tract road leading to the stream where sand mining is actively taking place.

Data collection

Plantation litter and soil collection

Two diagonal transect lines of 100m each were taken within 1haof the Teak, Gmelina and Bamboo forest plantation types in the reserve. The two diagonal lines were established in each of the three plantation types that is Teak, Gmelina and Bamboo to enable the location of 1m × 1m quadrants as permanent litter sampling points. These litter sampling points were at 20, 40, 60, 80 and 100m that is at 20m intervals along the established diagonal lines. This gave a total of 5litter sampling points per line transect and 10 L sampling points per plantation type which translated to 5 grab litter sampling points per plantation type.

Litter samples were carefully harvested with the hand garden fork from each quadrant every forth night for 10 weeks at the rate of5 and 10 L samples per transect line and plantation type respectively which translated to five grab samples per forest plantation type. Experimental soils of approximately 1.50m^3 were obtained from a depth of 0.30m in the established permanent litter sampling quadrants at the end of the 10 weeks litter collection from each of the three forest plantation types for use in the screen house experiment. The soil auger was used to collect grab samples of soil from the sampling quadrants in each forest plantation types at a depth of 0-30cm for laboratory analysis.

Germination trials

Three open germination beds measuring 150cm × 50cm × 30cm were prepared within the Teak, Gmelina and bamboo forest plantation type, taking the need for adequate sunlight into consideration. The beds were deliberately and carefully established in each plantation type with a view to maintaining the same nutrient

Table 1. Litter production capacity in the different forest plantations (t/ha, dry weight).

Period (Weeks)	Forest plantation type Bamboo	Teak	Gmelina
2	2.57^{b}	3.14^{b}	4.12^{a}
4	2.21^{b}	4.10^{a}	3.69^{a}
6	$2.65^{\mathbf{b}}$	3.63^{a}	3.58^{a}
8	2.85^{b}	4.05^{a}	3.53^{b}
10	3.05^{a}	3.18^{a}	3.07^{a}
Mean	2.67	3.65	3.60

Means with the same superscript on the same row are not significantly different ($P < 0.05$).

soil and litter source. They were established in relatively open spaces between standing trees within each plantation type and not directly under tree canopy. Sixty seeds of *Irvingia gabonesis,* which were obtained from a local market in Kwale, were planted out on each germination bed using an enspacement of 7.5 cm× 2.5 cm at the rate of 20 seeds per bed. These were then watered uniformly by sprinkling with an average of 8 L per bed/week to allow for consistent wetness and ensure that litter deposits were equally aided in the process of decomposition for mineralization of nutrients. These were monitored for emergence every week for a period of 6 weeks after which 10 germinated seedlings were selectively pricked from the germination beds of each plantation type and transplanted in 30 polypots already recharged with the experimental grab soil samples of forest plantation types of 10 replicates each in the Presidential Initiative on Afforestation screen house of the Ministry of Environment, Ogwashi Uku These were further monitored for over a period for growth variables of height, leaf area, collar diameter, and leaf-stem ratio.

Litter estimation and soil analysis

The harvested litter samples were oven dried at a temperature of $80^{o}C$ until a constant weight was attained. The weight of litter per grab sample of the quadrant was taken and averaged as litter production in each forest plantation type. It was in view of ensuring good representative samples of litters during harvest that a minimum of two diagonal transect lines were established per plantation type. This resulted in 10 L sampling points/quadrants measuring $10^{4}cm^{2}$ to give approximately 10% sampling size per hectare for each plantation type.

The soil samples were analyzed for bulk density, porosity, pH, organic carbon and matter. Bulk density was determined by oven-drying the soil samples to constant weight at 105°C and the bulk density derived as described by Klute (1986). Porosity was inferred from the bulk density. The pH was measured in 1:2.5 soils: water suspension as described by Dane et al. (2002). Organic carbon was determined using the Walkley and Black (1934) wet oxidation method as modified by Nelson and Sommers (1986) and the organic matter was computed by multiplying organic carbon the van Bermelen's factor of 1.725. Exchangeable cations (K^{+}, Ca^{2+}, Mg^{2+} and Na^{+}) were extracted with 1M NH_4OAc and the amounts in extracts were then determined using atomic absorption spectrophotometer (Thomas, 1982). Total nitrogen was assessed using the Kjeldahl nitrogen analysis method (Jackson, 1958). Exchangeable acidity was measured from 0.1M KCl extract and titrated with 0.1M NaOH (Juo, 1979). The effective cation exchange capacity was taken as the sum total of exchangeable cations and exchangeable acidity. Standard soil sample as prescribed for the various parameters. The data collected were subjected to analysis of variance (ANOVA) and significant means separated using the Duncan multiple range test (DMRT) at 5% probability levels. Inferential statistics (correlation and regression) was employed to analyze the data where appropriate.

RESULTS

Litter production capacity

The average litter production was higher in the Teak and Gmelina than the Bamboo forest plantation (Table 1). It ranged from 2.21t/ha in the Bamboo plantation to 4.12t/ha in the Gmelina plantation. However, within the forest plantation types, itranged from 2.21-3.05 t/ha to 3.07-4.12 and 3.14-4.10t/ha for the Bamboo, Gmelina and Teak respectively. The mean litter fall capacity was highest for the teak (3.65t/ha) and least for bamboo (2.67 t/ha).There was no significant difference in the mean litter fall and production among the three forest types at the tenth week. Nonetheless, there were significant differences between the Teak and Gmelina, Bamboo and Teak as well as Teak and Bamboo at second, sixth and eighth weeks of litter harvests respectively.

Physico-chemical properties of soils under different forest plantation

The physico-chemical properties of the soils of the 3 subgroup (Bamboo, Teak and Gmelina plantation types) are summarized in Table 2. The bulk densities of the soils under the three plantations varied significantly (Table 2). The highest soil organic matter (3.02%) was recorded in the Bamboo plantation which differed significantly from the Teak and Gmelina plantations that were statistically at par. With respect to the organic carbon, the trend was similar to that of organic matter as the Bamboo plantation showed the highest (1.75%) while the Gmelina (1.66%)

Table 2. Physical and chemical properties of soils under different forest plantation.

Parameter	Forest plantation type		
	Bamboo	Teak	Gmelina
Bulk density (g/cm^3)	1.45[b]	1.47[b]	1.59[a]
Porosity (%)	44.66[a]	44.40[b]	39.88[c]
Moisture content (%)	27.32[a]	23.30[b]	21.28[c]
Organic carbon (%)	1.75[a]	1.70[b]	1.66[b]
Organic matter (%)	3.02	2.93[b]	2.86[b]
Total nitrogen (%)	0.92[a]	0.76[b]	0.64[c]
Carbon-nitrogen ratio	1.90[c]	2.24[b]	2.60[a]
pH ($pH_{(KCl)}$- $pH_{(H2O)}$)	5.94[a]	5.80[b]	5.69[c]
Exchange cation (Meq/100g soil)	8.06[a]	5.50[b]	5.05[c]
Exchangeable acidity (Meq/100g soil)	3.44[a]	1.34[b]	1.29[b]

Means with the same superscript on the same row are not significantly different ($P < 0.05$).

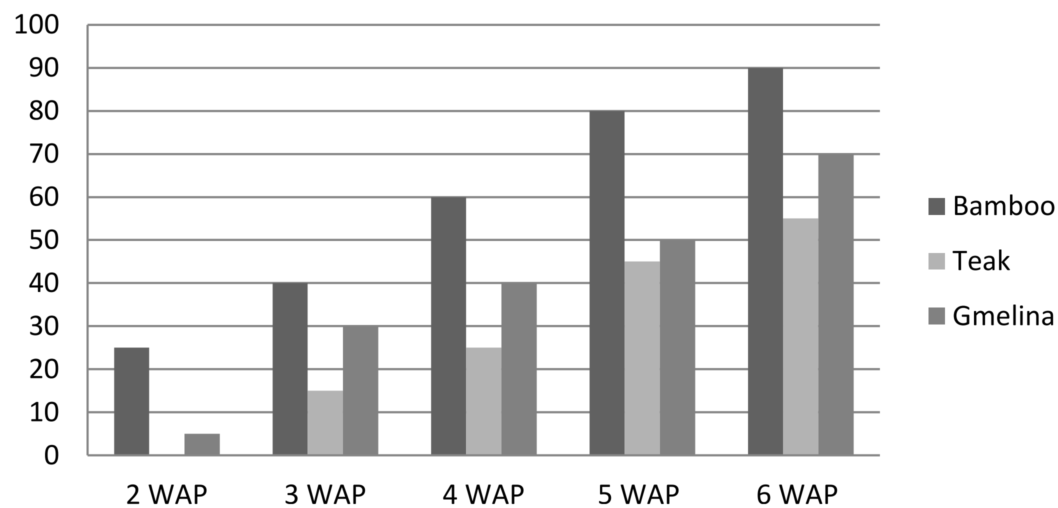

Figure 1. Germination percentage of Irvingina under different plantation soils.

had the least. The pH difference, ($pH_{(KCl)} - pH_{(H2O)}$), was positive for the three plantation forest soil types although were statistically not at par. However, the pH was highest in the bamboo forest plantation forest soil while the least pH of 5.69 was recorded by the Gmelina plantation. The soil physico-chemical properties were significantly correlated with each other. The correlation analyses of the various soil physical and chemical properties in the three plantation types are shown (Table 3). With respect to the Bamboo plantation soil, the organic matter was positively correlated with the bulk density ($r = 0.919$). This showed the contribution of organic matter to bulk density. The same result was recorded in the Gmelina ($r = 0.944$) and the Teak ($r = 0.998$) forest plantation soils. The pH showed negative significant correlation with organic carbon ($r = -0.404$) and CEC ($r = -0.667$) in the Gmelina plantation forest soils whereas in the bamboo forest soil pH showed positive correlation with organic carbon ($r =1.903$) and CEC ($r = 1.685$).

Germination trial of *I. gabonensis*

The germination percentage of Irvingia under the various forest plantation soils are shown in Figure 1. At two weeks after planting, the Bamboo forest soils recorded a germination percentage of 25% while the Gmelina forest soil was 5%. There was no germination in the Teak plantation forest soil. However, at three weeks after planting it was Bamboo soils (40%) >Gmelina soil (30%) > Teak soils (15%). The highest (90%) and least (55%) germination percentages were attained at 6 weeks after planting with the Bamboo and teak forest soils respectively.

Table 3. Pearson product moment correlation coefficient of the three forest soils.

Correlated variable	Bamboo	Teak	Gmelina
Bulk density vs. porosity	0.8850	0.9982	0.8205
Bulk density vs. organic carbon	0.9980	0.3973[ns]	0.9720
Bulk density vs. organic matter	0.9190	0.9998	0.9787
pH vs. Organic carbon	0.9030	0.9834	-0.4040
pH vs. Cation exchange capacity (CEC)	0.6850	0.9578	-0.6667

Table 4. Vegetative development of *I. gabonensis* seedlings under forest plantation soils.

	Forest plantation type		
Growth variable	Bamboo	Teak	Gmelina
Height (cm)	53.10 ± 3.82[a]	28.40 ± 2.28[c]	48.20 ± 2.17[b]
Leaf Area (cm^2)	47.19 ±1.04[a]	10.80 ± 0.23[c]	30.19 ±1.28[b]
Collar Diameter (cm)	3.05×10^{-1} ±0.44[bc]	3.61×10^{-1} ± 0.48[a]	3.23×10^{-1} ±1.31[b]
Leaf-stem ratio	0.43[a]	0.17[c]	0.33[b]

Means ± SD with the same superscript on the same row are not significantly different ($P < 0.05$).

The height of *I. gabonensis* seedlings varied significantly among the three plantation forest soils (Table 4). Plant height under the Bamboo litter forest soil, recorded a height of 53.10 ±3.82cm that significantly differed from the Gmelina (48.20 ± 2.17cm) and Teak (28.40 ± 2.28cm). Hence, it recorded the highest moisture content (27.32%) and the least by Gmelina forest soil (21.28%) with a corresponding high bulk density of 1.59g/cm^3. There was significant difference among the leaf areas of the different forest plantation soils. The leaf area showed similar trend with the plant height and the bamboo forest soil recorded the highest mean area of 47.19 ±1.04 cm^2 while the Teak (10.80 ± 0.23 cm^2) recorded the least leaf area. The leaf-stem ratio which is a measure of the change in botanical composition was highest in the Bamboo plantation forest soil (0.43) and least in the Teak forest plantation soil (0.17).

DISCUSSION

The mean litter production was Gmelina (3.65 t/ha) > Teak (3.60 t/ha) > Bamboo (2.67t/ha)was quite low compared to the estimated litter fall of 7.50 -7.80t/ha in the Sakponba Forest reserve (Onweluzo E, 1970) and 5.60-7.30t/ha for the Gambari forest reserve (Ola-Adams and Egunjobi, 1992). The low litter fall in the Teak and Gmelina plantations could be due to the high timber and fuel-wood extraction rates in the Ogwashi-Uku forest reserve as it was established for poles and timber, to forestall the accelerated rate of deforestation and fragmentation of its status as protected area (FORMECU, 2000; Onojeghuo and Onojeghuo, 2015). However, with respect to the individual number of leaves per quadrat at the various points on the transect lines the Bamboo recorded a remarkably higher quantity, but for the larger leaf sizes of the Teak and Gmelina in comparison with that of Bamboo. This to a large extent shows that while tree species could have high litter fall capacity, the size of leaf could also account for its proportionate contribution to the soil organic matter and nutrient status in a given period of time. This finding agrees with Indriyanto (2009) that litter produced by a forest is related to different amount and composition based on the structure and the species diversity of the plant. Notwithstanding, the nutrient mining capacity could also vary with the available environmental conditions that can enhance or retard the decomposition depending on the interplay of critical elements particularly in presence of oxygen and nitrogen.

The rooting structure that actually proliferate the upper 0-30cm as well as its slower decomposition and infusion may have accounted for the favorably low bulk density of the bamboo plantation soil because of the nature of the glossy leaf surface and structure respectively. Hence, unlike the Teak and Gmelina, the bamboo surface offers additional resistance to decomposing organisms which invariably increases the phytocycling process. This delay commensurately ensures that nutrients are mined from the litters at a steadier rate and readily available state that make for retention in soil. The Teak and Gmelina could have faster decomposition rates that lead to loss of nutrient through leaching. There was however no significant difference between the bulk densities of the Teak and Bamboo. This agrees with Johnson and Curtis (2001) who stated carbon losses may result from leaching and soil erosion.

The three forest soil types are relatively acidic in nature and are therefore fertile since the availability of nutrients for plants is influenced by the soil pH (Zhao et al., 2012). However, the pH was highest in the bamboo forest plantation forest soil which could be as a result of the increasing carbon potentials of the soil due to steady litter mineralization rate which may have accounted for the acidic accumulation in comparison to that of the Teak and Gmelina. The high mineralization rate could have led to its prompt leaching downward from the upper horizon. The soil organic matter content of the three plantations were quite high (≥ 2.50%) according to classification of Adepetu (1986). This may not be unrelated with the fact that all the soil samples were taken from the same soil depth. However, the highest soil organic matter of the bamboo plantation may not be unrelated with the slower phytocycling potential of the needle leaf shape structure which leaves behind much of the leaf materials in the soil as organic matters.

Furthermore the rate of litter deposition varies widely among species in identical ecological situations (Wardle et al., 1997; Perez-Harguindeguy et al., 2000). On the other hand, the Teak and Gmelina did not differ significantly as the leaves have almost similar leaf surface quality. Hence, the results are quite suggestive of the decomposition rate of these veins and other leaf parts in the process of phytocycling which could be deemed lower in the Bamboo than in the Teak and Gmelina plantations.

The lack of significant difference between the organic carbon of the Teak and Gmelina plantations agrees with the finding of Wang et al (2013) which indicated that bamboo forest ecosystem through its high photosynthetic mechanism turns more carbon dioxide (CO_2) into organic carbon which are stored in leaf structures that eventually become litter components of the forest floor. The higher organic carbon content of Bamboo soils could be due to the presence of dense fine root on the top layer of the soil as reported by Paudel and Sal (2003).

Furthermore, the leaf-shedding potential of bamboo is reported to be quite high because its leaves usually fall at earlier age of between 12-18 months (Haettenschweiler et al., 2011) which could yield an above ground litter value of 4.1-7.2tons/ha in 2 years (Wang et al., 2013). Although the Teak and Gmelina have broad leaves which could have contributed to the organic matter and carbon contents of each plantation, the capacity to restrict oxygen diffusion into the soil particularly when wet (or green) could have equally limited the phytocycling rates leading to a commensurate decline in nutrient infusion into the forest soil.

Gmelina and Teak plantation forest soils in comparison with the Bamboo forest soil recorded the least C/N ratio which depicted the high mineralization rate of the bamboo forest litters. This finding agrees with Mafongoya et al. (1998) which suggest that litter materials with high N and low carbon-nitrogen ratios mineralize quicker than those with low N and higher C/N ratio. Furthermore, the mean C/N of each forest plantation type is also suggestive of the dominant active microbial biomass. High C/N ratio indicates fungal dominance of a microbial community whereas a low ratio suggests the prevalence of bacteria (Anderson and Domsch, 1989) and hence could be extrapolated that the microbial community in the *T. grandis* and *G. arborea* forest plantation soils are likely dominated by fungi. This may have accounted for the poor mineralization potentials and low organic materials recorded.

The early and high germination percentages recorded in the bamboo forest soils may be related with its high moisture content and improved porosity which is critical to the decomposition and mineralization processes. The high root proliferation capacity of Bamboo may have accounted for a constant moisture content that facilitated the advanced germination, enabling the bathing of the protoplasmic mass of the Irvingia seeds in the germination beds under the bamboo forest plantation, when compared with the tap-rooted *T. grandis* and *G. arborea* forest plantations that tended to pull water from the soil but cannot retain the same in the upper root biome due to the absence of specialized root structure typical of the bamboo forest. This finding is in line with Pandel and Sah (2003) that reported that the presence of dense fine roots on top layer of soil and higher organic carbon content results in high water holding capacity. Improved porosity observed in bamboo may have facilitated respiratory activities in germinating embryos.

The highest plant height recorded under the Bamboo litter forest soil may not be unrelated with the favorable bulk density of the bamboo forest soil due to its characteristic rooting system that often permeates the root biome and thereby increasing aeration and enhancing the macro-pores spaces for more water retention and release. The capacity of Bamboo not only to grow in relatively poor soil but to equally and efficiently make use of the available nutrients to build up relatively fertile soil around the clumps (Hairiahet al., 2006) could have contributed to the positive effect of the forest type on the soil.

The highest leaf-stem ratio which is a measure of the change in botanical composition recorded in the Bamboo plantation forest soil is an indication that the level of photosynthates accumulation is highest in the bamboo forest soil which may be connected with the relationship between the nutrient bioavailability. The significantly higher growth performance recorded in soil with higher total organic carbon is not unusual since soil organic matter governs soil physical and chemical properties, ensures abundance of the concentration of essential nutrients and provides favorable conditions for plant survival, development (Horwath, 2005)

Conclusion

The litter production capacity of the three evaluated forest plantations showed that the Teak and Gmelina were predominantly higher than the Bamboo forest. However, this did not translate into commensurate nutrient richer soils in the *T. grandis* and *G. arborea* forest plantations, perhaps, due to the faster decomposition rate of these forests unlike the Bamboo forest plantation. This may have accounted for the significant positive effects on the germination trial and vegetative development of *I. gabonensis* by the Bamboo forest plantation soils as indicated by the highest germination rate, plant height, leaf area and the leaf-stem ratio which are critical tree growth indicators. This therefore revealed that the forest soils from the Bamboo plantation represent potential nutrient sources for the growth of Irvingia especially in the deforested soil resource depletion crisis in the Ogwashi-Uku Forest Reserve. The result therefore offer significant clue as to its usefulness as edaphic bridge in various *ex-situ* nursery and forest regeneration activities for the development of *Irvingia* as well as other related indigenous forest tree species that have crucial nursery to establishment challenges.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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