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NUTRIENT - USE EFFICIENCY OF *TECTONA GRANDIS* (LINN. F.) SEEDLINGS ON BASEMENT COMPLEX AND FERRIC LUVISOL SOILS OF IBADAN, NIGERIA

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ABSTRACT

The study investigated the use-efficiency of selected soil nutrient elements - Nitrogen (N), Phosphorus (P) and Potassium (K) in the synthesis of dry matter by *Tectona grandis* (Linn.f.) seedlings. *T. grandis* seedlings were grown on basement complex and ferric luvisol soils for 77 days after transplanting (DAT). Sixty polythene pots were filled with each soil type. Sixty soil-seedling samples formed an experimental unit that was replicated three times making a total of 360 seedlings. Eight seedlings were selected at intervals of 7 days for the first 28 DAT and four seedlings for the remaining 42 DAT in each experimental unit. Composite samples of soil media and seedlings were taken at intervals of 7 days and chemically analyzed. The dried shoot and leaves were combusted at 500°C, for carbon content determination. Range of daily light intensity during the experiment was 3.5 to 6.2 Klux while daily mean temperature was 24.7 to 27.5°C. Total carbon and biomass results showed that photosynthetic efficiency and photosynthetic carbon production of seedlings grown on basement complex were not significantly different from those of ferric luvisol. It is concluded that an increase in biomass could not be a major indicator of an increase in biomass carbon production. Therefore, photosynthetic efficiency alone may not be an adequate indicator of efficient photosynthetic carbon fixation. The root/shoot ratio was higher than 1.0 in both soils, indicating higher biomass allocations to the roots of the seedling. The study provides basis for the estimation of the phosphorus and nitrogen-supplying power of ferric luvisol and basement complex soils,

Key words: nutrient use - efficiency, NPK, *Tectona grandis*, total carbon, carbon biomass, basement complex, ferric luvisol.

INTRODUCTION

Organic matter is a critical factor in determining the potential of tropical soils. It influences the structure of the soil and thereby, affects water infiltration and storage, aeration and root penetration. In humid tropics, organic matter is a major source of nutrients and cation exchange capacity (Young, 1976). Quantifying soil organic matter and nutrient dynamics in relation to ecosystem management is fundamental to identifying pathways for soil carbon sequestration (Post *et al.*, 1990). Plant material is the major source of soil organic matter. Soil organic matter content ranges from less than 0.2% in desert soils to over 80% in peat soils. In temperate regions, soil organic matter ranges from 0.4 - 10.0%; while in tropical regions it ranges from 3.0 – 4.0% as well as from 1.0 - 3.0% in semi arid areas (Smith *et al.*, 2000).

As a general guide, top soil organic matter content in the forest zone may be considered low if it falls below 3.0% and 2.0% for soils with sandy-clay to clay and sandy - clay - loam to sandy - loam, respectively (Young, 1976). Agboola and Ayodele (1987) considered < 3.0% organic matter as low, 3.4

to 4.8% as medium and above 4.8% organic matter as high for a tropical forest soil. Tate and Salcedo (1988) observed that the ratio of the quantity of carbon in a soil to that of nitrogen, phosphorus, and sulphur remains approximately constant, whatever the level of organic matter in the soil. Soil N : C ratios tend to be in the range of 1:10 to 1 : 20 (Post *et al.*, 1985), foliar N : C ratios are typically 1 : 25 – 1:50, and wood N:C ratios tend to be about 1 : 500 to 1 : 1000 (Jeffreys, 1999). Hence, any shift of nitrogen from the soil to wood would lead to a large increase in site carbon storage even without the input of any additional nitrogen into the system. Generally, savanna soils have low nitrogen status and high C : N ratios than forest soils.

In Nigeria, most suitable areas for *Tectona grandis* establishment are confined to the drier high forest with annual rainfall of 1270 – 1524 mm, on basement complex soils. Fertile soils with a substantial clay fraction, free of stones, well drained and with a pH range of 6.0 – 7.5 are preferred (Jenkin, 1961).

Sometimes, limiting nutrients may be more than one. Species differ in their relative nutrient requirements, in their ability to take up and use the nutrients available at the site, or in their responsiveness to enhanced nutrient supply (Ryser *et al.*, 1997; Aerts and Chapin, 2000). Koerselman and Meuleman (1996) suggested that biomass production of the vegetation is almost always limited by nitrogen if the N : P ratio of the aboveground biomass is low (< 14) and by phosphorus if the N : P ratio is high (> 16). However, Lechowicz and Shaver (1982) suggested that the effects of nutrient availability on biomass nutrient contents involve growth-form specific patterns. Furthermore, it was suggested that biomass N : P ratio reflects the relative availability of N and P to plants and may indicate the degree of N or P deficiency experienced by plant (Guswell *et al.*, 2003).

Thus, reafforestation and restoration strongly rely on seedling growth and survival. Information on early seedling growth and nutrient allocation is required for successful restoration programme (Du *et al.*, 2008). In trees, a small increase in relative growth at the early stage can result into large differences in size of individuals at the end of the first year growth, even after a number of years. The study evaluated the biomass accumulation of *Tectona grandis* when exposed to two types of soil.

MATERIALS AND METHODS

Study site

The study was carried out in a greenhouse of the Department of Forest Resources Management, University of Ibadan, located on latitude $7^0 26'$ and longitude $3^0 54'$ at 277 m asl. It is in the dry high forest zone (Adedokun, 2000). The climate is the West Africa monsoon type with dry and wet seasons

The mean annual rainfall is approximately 1259.57 mm, with two rainfall peaks occurring in the months of June and September/October. Minimum and maximum annual relative humidity are 54.50% and 95.30%, respectively. Daily temperature of Ibadan fluctuates between a minimum of 19^0C at night and maximum of 31^0C during the day, with variation throughout the year.

Experimental setup

Viable seeds of *T. grandis* were soaked in flowing stream (running water) for 14 days, and were thereafter sown on seed beds and covered with a thin layer of soil. Twenty - one (21) days after germination, 360 uniform and vigorous seedlings were selected and transplanted into the pots prepared for the experiment.

The basement complex and ferric luvisol soil samples were taken to a depth of 15 cm in a grid pattern of 30 m by 30 m at various spots in both Gambari Forest Reserve (basement complex soil) and University Teak Plantation (ferric luvisol). The university teak plantation is predominantly ferric luvisol (Moorman *et al.*, 1975); while the parent rock of Gambari soil is crystalline and it is a part of a pre-cambrian series shown as 'undifferentiated' basement complex on the geological map of Nigeria (Mackay, 1923).

Samples of top - soil (0 - 15 cm) per site were homogenized and composite samples taken for chemical analysis. Initial total nitrogen (N), available phosphorus (P), Potassium (K) and Cation Exchange Capacity (CEC) of the soil were measured. Basement complex and ferric luvisol soils were cleared of large stones and plant debris; sieved through 2 mm sieve and kept under room temperature until the commencement of the experiment. A total of 360 polythene pots (diameter = 14 cm, height = 25 cm) were used for this study. Sixty (60) polythene pots were each filled with 1.5 kg basement complex soil while an equal number of pots were filled with same quantity of ferric luvisol. The soil in polythene pots were brought to field capacity with addition of tap water, and then the seedling were pricked - out and transplanted into the polythene pots, at 2 - leaf stage. Only seedlings of uniform height (6.0 cm) and size were carefully selected and transplanted. Moistening of seedlings was done twice each day. Fourteen (14) days after transplanting, growth parameters (leaf and shoot-root weight) were measured at a 7 - day intervals for 77 days after transplanting (DAT).

Sampling of seedlings

Within the first 28 DAT (given the small seedling sizes at this age), eight seedlings, representing the range of collar diameters, were selected at 7 - day intervals from each experimental unit to assess dry matter and calibrate nutrient uptake. Only four seedlings were selected per week to assess dry matter and calibrate nutrient uptake for the remaining period of the experiment. To assess biomass, the selected seedlings were carefully uprooted and their roots rinsed with water to remove soil particles. The leaf areas of the seedlings were traced on graph paper and thereafter, taken to the laboratory where they were separated into the root, shoot and leaf components. The different components were then oven dried at 60^{o}C until constant weight was attained and re-weighed using electronic balance (Metler P 163). The differences in successive values obtained from seedling dry matter at weekly intervals were used to compute the Relative Growth Rate (RGR) as suggested by Hunt (1978).

The air temperature and light intensity were measured using thermometer and light meter (EEL LIGHT MASTER PHOTOMETER, Halstead Essex), respectively. Measurements of air temperature were made at 6 hour intervals while light intensity was made at 3 hour intervals over the plant canopy, and the data were used in computing average daily temperature and light intensity, respectively.

Chemical analysis

Soil nutrient concentrations were determined from soil samples collected at 7 - day intervals from each experimental unit. The samples were air - dried and mixed, and a subsample was sieved to < 2.00 and < 0.5 mm prior to extraction in the laboratory. Soil available phosphorus was extracted by mehlich - 3 extraction solution and measured colourimetrically by molybdate blue method (Golterman *et al.*, 1976). Aliquots of these extracts were used to measure soil potassium concentration by flame photometry. Total nitrogen was determined by micro - Kjeldahl and steam distillation method. Organic carbon was determined by using wet combustion method (Murphy and Riley, 1962), and then converted to soil organic matter by multiplying by a constant (1.72). Particle size analysis was obtained by hydrometer method. Sub - samples (1.5 g) were dry - ashed at 500⁰C for 8 hours after which the ash weight was subtracted from initial weight to derive the weight of carbon lost. Soil pH was measured with a pH meter and glass plus reference electrode (1 : 2 soil/ water ratio). Extractable Ca, Mg, and K were determined by extraction with glacial acid of ammonium acetate solution at pH 7.0 and atomic absorption spectrophotometry (Spectronic (R) 20 Genesis).

Data analysis

Significant difference in biomass carbon, between soils, was determined with two tailed paired t - test. All statistics were computed with STATISTICAL for Windows 5.0.

RESULTS AND DISCUSSION

The course of the mean temperature and light intensity within the seedlings growth medium during the growing season are indicated in Figures 1 and 2.

The highest temperature was recorded 70 DAT; corresponding with the peak of light intensity. Temperature profile had two peak values (14 and 70 DAT) and lowest value in 35 DAT. Light intensity (Klux) increased progressively from 14 to 77 DAT (Figure 2). The light intensity ranged from 3.5 to 6.2 Klux with a mean value of 4.6 Klux. Temperature, on the other hand, ranged from 24.7 to 27.5°C with mean temperature of 26.2°C.

The soil textural classes of basement complex and ferric luvisol are sandy loam and loamy sand, respectively, with 66 to 75% sand at each sampling point. Both soil types were low in organic carbon, exchangeable bases (CEC < 2.0 meq/100 g) and pH was almost neutral (pH = 7). The low mean CEC could be attributed to low organic matter (OM) contents of the sites. According to Asadu *et al.* (1997), organic matter of soils in sub - Saharan Africa alone could account for about 60% of the mean Effective CEC of soils and silt also contributes significantly to effective CEC

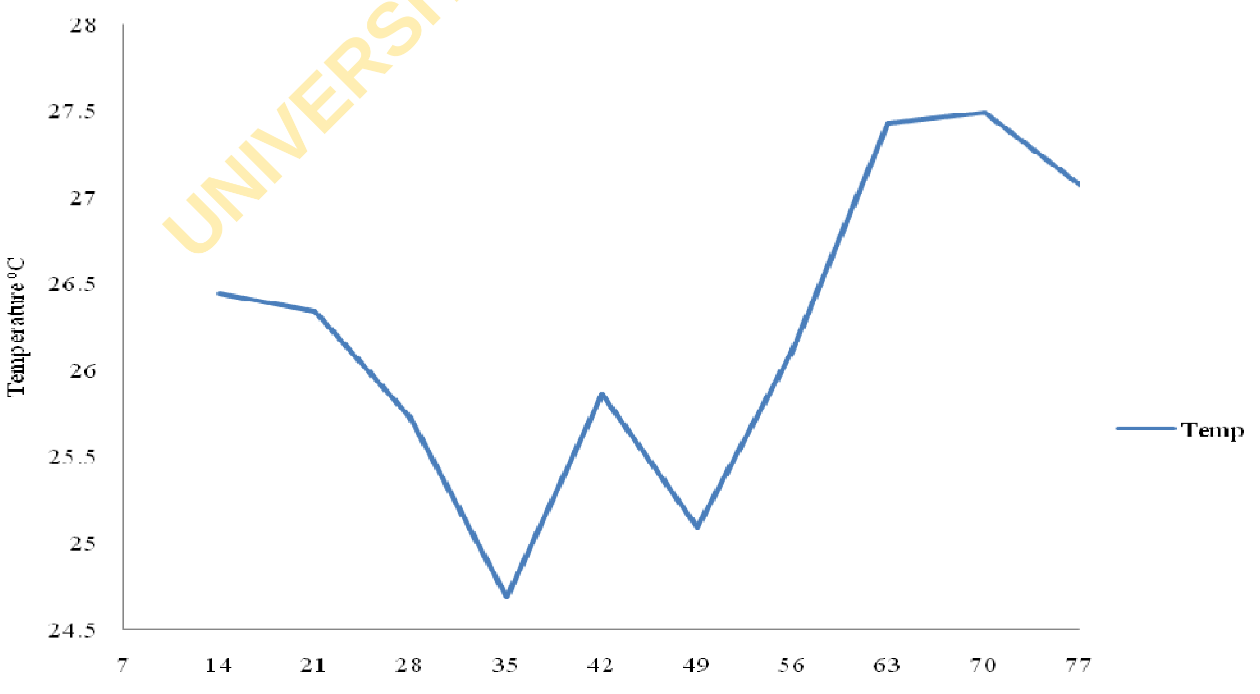

Figure 1: Average daily temperature of the seedling growth medium during the experiment

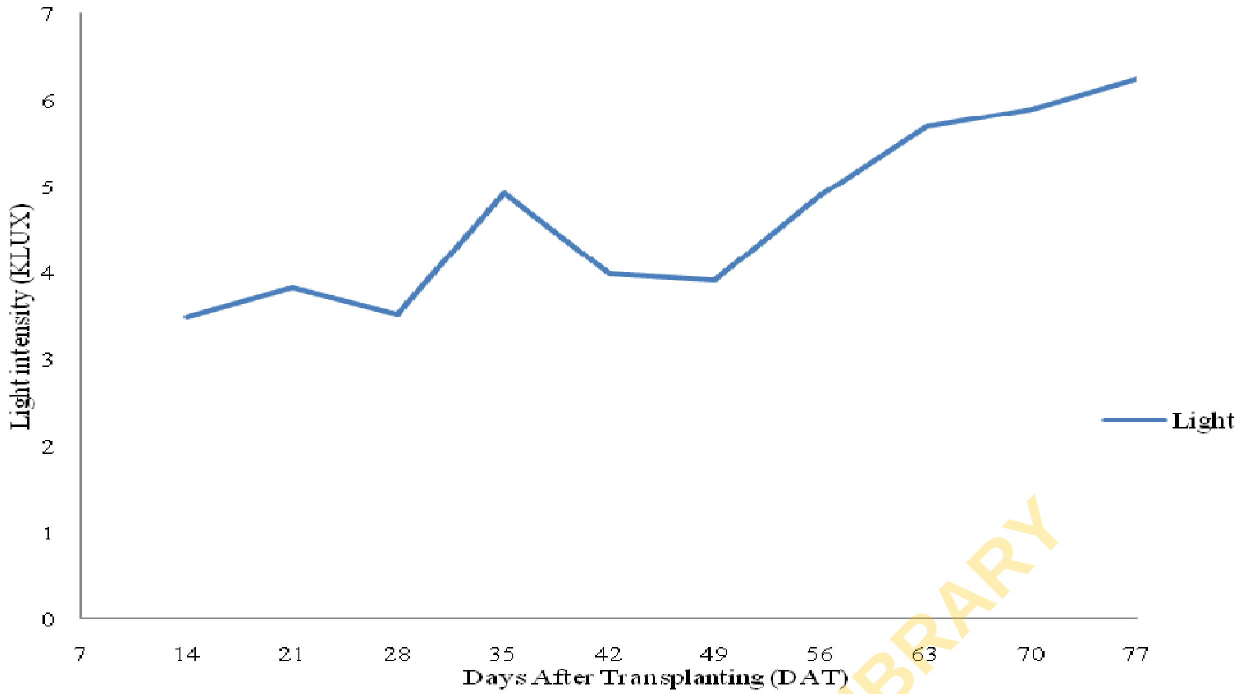

Figure 2: Average daily light intensity in the seedling growth medium during the experiment

organic carbon differences result from changes in land management. Nitrogen is a growth limiting nutrient in most luvisol (Robertson and McGill, 1983). In Canada, Grayic luvisols have a thin A - horizon, which is almost neutral (pH 6.0 - 6.5) with low organic carbon content (10 - 20 g/kg) and nutrient-supplying capacity (Broersman *et al.*, 1996).

The plant had a dry matter yield of 0.47 to 5.8 g on basement complex and 0.3 to 3.6 g on ferric luvisol over the 77 DAT period (Figure 3). *T. grandis* seedlings grown on ferric luvisol had 26.3% of its dry matter in the root while that of the seedlings grown on basement complex was 28.9%. Moreover, approximately 51.2 to 52.2% of dry matter was stored in the leaf.

The decline in dry matter at 63 DAT on basement complex and 56 DAT on ferric luvisol were mainly due to initiation of ontogeny (self-shading), root restriction and even soil compaction due to the shape and size of the polythene pots. Consequently,

Table1: Initial chemical properties of basement complex and ferric luvisol soils

Parameters	Unit	Basement complex	Ferric luvisol
Org.Carbon	mgkg^{-1}	2.2	2.2
Total N	mgkg^{-1}	0.2	0.3
Available P	mgkg^{-1}	6.0	30.8
Available K	mgkg^{-1}	1.2	1.4
Exchangeable Ca	cmol kg^{-1}	5.5	6.0
Exchangeable Mg	cmol kg^{-1}	5.7	6.0
Sodium ion (Na)	cmol kg^{-1}	0.8	1.0
CEC	meq/100g	1.1	1.1
pH		7.0 ± 0.3	6.2 ± 0.2
Fine sand	gkg^{-1}	666.0 ± 3.0	746.0 ± 2.0
Silt	gkg^{-1}	274.0 ± 2.0	174.0 ± 2.0
Clay	gkg^{-1}	60.0 ± 2.0	80.0 ± 2.0

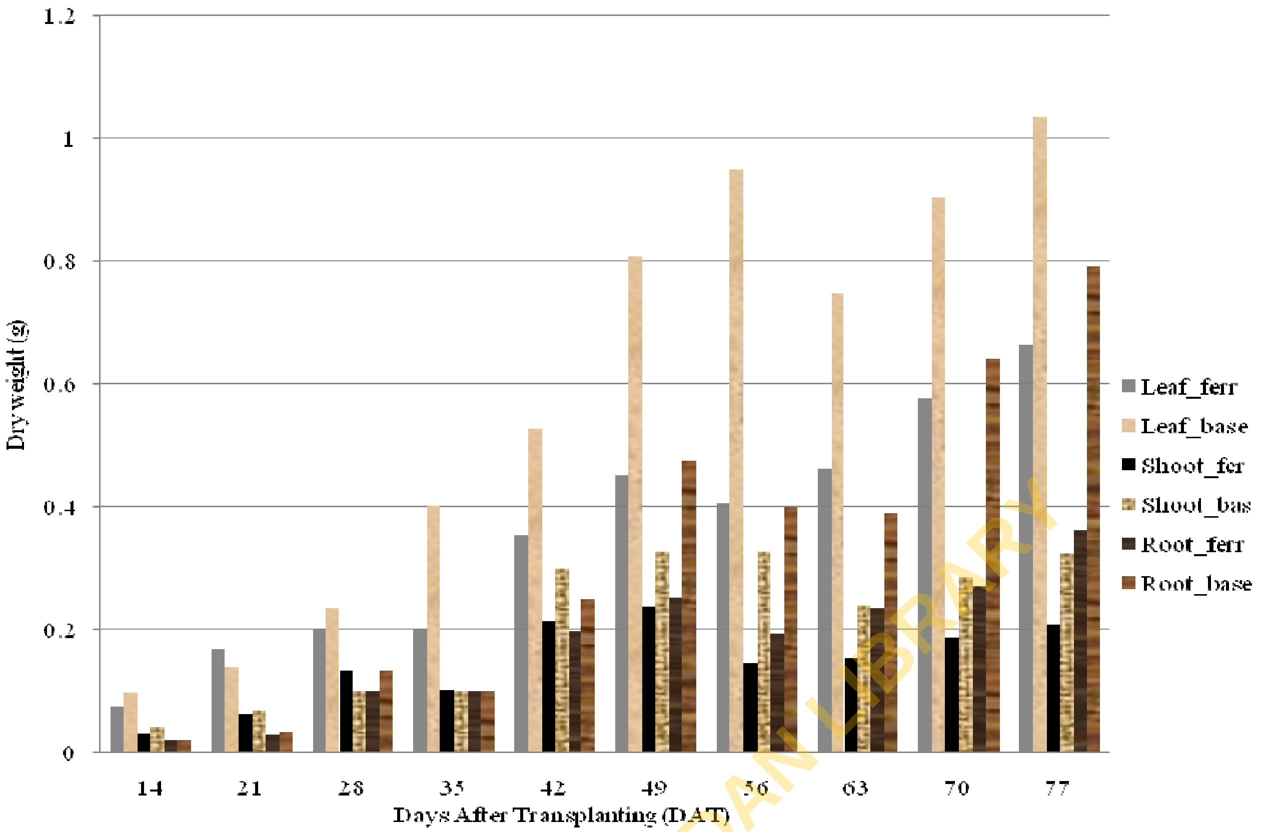

Figure 3: Leaf, Shoot and Root dry weight of *Tectona grandis* grown on basement complex and ferric luvisol

Table 2: Nutrients components of soil media and *Tectona grandis* seedlings

	Basement complex			Ferric luvisol		
Nutrient	Shoot	Leaf	Soil	Shoot	Leaf	Soil
Nitrogen(mg/g)	1.9±1.4	3.6±1.9	0.3±0.3	1.2±0.7	2.5±1.4	0.3±0.1
Phosphorus(mg/g)	0.3±0.2	0.5±0.3	21.3±2.2	0.1±0.0	0.2±0.1	5.4±0.5
Potassium(mg/g)	0.9±0.4	0.9±0.3	0.8±0.4	0.7±0.2	0.6±0.2	0.7±0.4
Org. Matter(g)	0.5±0.3	0.6±0.3	3.5±0.1	0.3±0.1	0.4±0.1	3.6±0.1
C/N	0.30	0.15	-	0.26	0.14	-
N/P	6.30	7.20	-	12.00	12.50	-
Total Carbon(g/kg)	77.5±0.05	82.4±8.3	2.0±0.1	80.7±0.7	77.4± 0.4	2.1±0.1

Table 3: Root : Shoot (R : S) ratio, relative growth rate (RGR) and leaf nitrogen concentration of *T. grandis* on two soil types

DAT	Seedling on basement soil			Seedling on ferric soil		
	R:S	RGR	Leaf N	R:S	RGR	Leaf N
14DAT	0.4	0.0	0.8	0.7	0.0	0.7
21DAT	0.5	0.3	0.6	0.5	0.7	1.1
28DAT	1.3	1.0	2.2	0.8	0.7	0.9
35DAT	1.0	0.1	3.0	1.0	0.1	1.3
42DAT	1.0	0.3	4.5	1.1	0.5	2.5
49DAT	1.4	0.7	5.0	1.1	0.5	3.0
56DAT	1.4	0.1	5.3	1.4	0.0	2.4
63DAT	1.7	0.2	4.1	1.5	0.2	3.6
70DAT	2.2	0.2	5.1	1.6	0.2	4.2
77DAT	2.5	0.1	5.7	1.7	0.2	4.8

these hindered shoot development. Physical restriction of root development could also possibly inhibit oxygen, water and nutrient uptake. The dry matter reduction is indicated by 21.8% and 26.8% for basement complex and ferric luvisol, respectively. In spite of differences in chemical properties between soils, the dry matter yields of both soil types were quite similar until 28 DAT (Figure 3). Relatively, seedlings grown on basement complex allocated more phosphorus and potassium to leaf structure than other parts of the seedlings (Table 2). Thus, the C/N ratio of the leaf was more than of the shoot structure on both soil types. The leaf and shoot structures of seedlings grown on ferric luvisol had higher N/P ratios than basement complex. The N/P ratios above 16 are typical of sites limited by phosphorus and values below 14 are typical of sites limited by nitrogen (Koerselman and Meuleman, 1996 and Gusewell, 2004). Thus, foliar N/P ratios below 14 support the view that both soil types are limited by nitrogen.

Higher soil nutrients (N, P and K), though lower organic carbon, in basement complex reflect corresponding higher shoot and leaf organic matter than ferric luvisol. The optimum organic matter content of seedling grown on basement complex is almost twice that of ferric luvisol (Table 2).

The t - test indicated that the leaf total carbon of seedlings grown on basement complex (paired sample t-test, 77.5g/kg: $P < 0.05$, $n = 10$) did not differ significantly from that of seedlings grown on ferric luvisol (paired sample t-test, 77.4 g/kg: $P < 0.05$, $n = 10$). Also, shoot total carbon of seedlings grown on both soils were not significantly different ($P < 0.05$, $n = 10$) from each other. The implication is that seedlings grown on basement complex would return more organic matter into the soil than those grown on ferric luvisol, although, basement complex had lower organic carbon (2.0 ± 0.1) compared to ferric luvisol (2.1 ± 0.1) (Table 2). The rapid increase in biomass yield could be due to increased mineralization of organic carbon, since the initial organic matter contents were almost the same for both soils (Table 1). Thus, total carbon and organic matter contents suggested that photosynthetic efficiency and carbon production (fixation) of seedlings on basement complex were higher than those on ferric luvisol. Low C / N ratio usually indicate a fast decomposition rate (Berg and McClaugherty, 2003).

There were progressive increases in root / shoot ratio as from 49 DAT, indicating higher biomass allocation to root part of the seedling. Although mean root mass of seedlings grown on ferric was lower than basement, the difference was not significant ($P < 0.05$). Overall, root / shoot ratio was higher than 1.0 in both soils, indicating higher biomass allocations to the roots of the seedlings. A root / shoot ratio higher than 1.0 should be expected for species adapted to water and nutrient deficit environments. Root / shoot ratio is constantly higher for basement soil. A high value of root / shoot ratio is expected when there is a great limitation of nutrients instead of light (Hoffmann and Franco, 2003). The mean RGR of the basement complex was 2.40 gg^{-1} day^{-1} and that of the ferric luvisol was 2.50 gg^{-1} day $^{-1}$. Plant tends to have low RGR towards the last days due to self - shading or to a large investment in supporting structures.

CONCLUSION

It is concluded from this study that *T. grandis* seedlings grown on basement complex would return more organic matter into the soil than those grown on ferric luvisol. Although the capacity of both soil types to fix carbon was not significantly different, basement complex soil would enhance plant ability to fix carbon dioxide. It is concluded that an increase in dry matter yield could not be a major indicator for an increase in biomass carbon production. Therefore, photosynthetic efficiency alone may not be an adequate indicator for efficient photosynthetic carbon fixation. Thus, seedlings that have higher growth rate in terms of dry matter yield would have higher allocation of photosynthate to leaves. The results support the view that both soil types are limited by soil nitrogen. Furthermore, it has long been suggested that biomass allocation to roots and root enlongation allow *T. grandis* seedlings to withstand the dry season during the first stage of life and they equally allow plants to re - sprout from underground organs after incident of fire. The results should enhance appropriate silvicultural regimes that promote low carbon land management practices. The ability to predict effects of modified nutrient availability on species composition would, therefore, help to choose appropriate management strategies. This study is thus a preliminary research effort to build a rapid assessment tool, as to which soil properties are most limiting to teak performance.

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