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Litterfall Decomposition and Nutrients Release in Yatta Teak Plantation Forest in Western Equatoria State, South Sudan*

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Abstract: This study assessed litter input in a teak plantation forest, and characterized soils, litter decomposition and elements release in Yatta forest, Western Equatoria State, South Sudan; during May 2008 and October 2011. Litter fall was collected weekly from plots of 16 m^2 under the forest cover with ten replicates. Seventy five litter bags were used to assess decomposition and elements release, and buried at 15 to 30 cm soil depth; 25 bags were withdrawn at 6, 12 and 18 months. The soil is an Oxisols, clay loam to clayey, acidic, rich in organic matter, and amply furnished with nutrients. Litter input was 1404.4 kg/ha/year; with concessive maxima and minima in dry and wet months. Losses of dry matter were high, with ranges of 52% to 95% during the tested periods. The elements carbon, nitrogen, phosphorus, potassium, calcium, magnesium were rapidly released with successive rates: 77.2%- 98.7%, 89.5% – 98.8%, 23.2% – 96.3%, 99.8% – 100%, 92% – 99.3%, 70% – 96.3% during the trial months. The results showed a high potential fertility of this teak plantation site and which will support the sustainability of the growing stock.

Keywords: Teak Plantation; Soil Characterization; Litterfall and Decomposition; Elements Release

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INTRODUCTION

Plantation forests are established to supply goods and services for the growers. Wood, non-wood, environmental and ecological conservation are among the goods and services expected to yield from plantation forests. Litter (including foliage, twigs, followers, fruits, bark) is part of non-wood products rendered by forests in general to terrestrial ecosystems (Wu *et al.*, 2010). But seldom is it given any due attention as a good. Even though, it is the most dynamic product of forests during their lifetimes (Xiaogai *et al.*, 2013). Litter input expresses the notion of biogeochemical cycle of solutes and elements in the soil-plant-atmosphere system. Thus, litter plays very important role in circulating organic carbon and organic and nutrient elements between the compartments of this system (Russell, 1973; Duchaufour, 1984; Binkley and Menyailo, 2005). And as such litter affects to a great deal the potentials of sites quality by improving their fertility; and whereby this fertility improvement can benefit for the establishment of the subsequent crops (both forest and agricultural) in those sites. To achieve this objective litter can be amassed in forested ecosystems and decompose in-situ or be collected, transported and incorporated in targeted sites.

Litter or organic matter decomposition, is influenced by many factors including, litter quality, climatic and edaphic conditions and biological activity (Swift *et al.*, 1979; Giweta, 2020; Morffi-Mestre *et al.*, 2020; Chen *et al.*, 2021). In favouring conditions litter decomposition is very quick and the produced materials are rapidly incorporated into the soil or leached out of it; while it is very slow in low temperature or water bogged areas and the litter usually tends to accumulate on the soil surface, often leading to formation of peat deposits (Duchaufour, 1984; Andriesse, 1988; Huat *et al.*, 2011).

The general objective of this study was to assess the biological cycle of organic matter and nutrient elements in a teak (*Tectona grandis* L.) plantation forest in a humid tropical region. The specific objectives were, characterization of soils under plantation forest; Assessment of litterfall in put (quantity and quality); and assessment of litter decomposition and nutrient release.

MATERIALS AND METHODS

Study site

The study was conducted in Yatta tropical forest (lat: 4° 44′ 44″ - 4° 46′ 28″ N and 28° 42′ 25″ - 28° 44′ 33″ E) located in Yambio County, Western Equatoria State, South Sudan.

The climate is of tropical humid type that has a bimodal rain seasons from March to July, with dry spill from second week of July up to first week of August. Then heavy rainfall occurs from August to November. The period December to February is dry season. Annual rainfall ranges between 1350 and 1600 mm; meanwhile, temperatures range between 24 and 32 °C, the highest temperature is recorded in February and the lowest temperature is 18 °C in August (Kingdon, 1989; Smith, 1949).

The geological formation of the area is composed of Basement Complex and the Nubian Sandstone. The superficial formation is mainly lateritic deposits of ironstone ferruginous red loams, forming a sheet that covers much of Western Equatoria. Ferralsols develop from this formation, they are strongly weathered soils, and therefore primary and secondary minerals of great stability characterize them. Quartz is the main primary composition, the clay composition or fraction consists mainly of goethite in accordance with the parent rock (Driessen, 2001).

The topography is a green belt plateau situated at 550 – 700 m *a.s.l*. The area is mainly ironstone plateau, with undulating hills. At the bottom of the hills are formations of depressions that act as drainage for surface runoff water and delivering it to the streams.

The vegetation is of humid tropical type that is influenced by anthropogenic activities. Natural broad leaved deciduous trees with open canopy are predominant for examples, *Terminalia sp*., *Combretum sp*., *Isoberlinia doka*, *Khaya sp*. Grass covers of *Aristida adscenious*, *Bidem pilosa*, *Boerhavia diggusa*, *Dactyloctenium aegytuim*, *Eleusine Indica*, *Euphobia hirta*, *Hyparrhenia rufa*, *Imperata cylendrica*, *Panicum maximum*, *Paspalum commersonii*, *Sporobolus pyramidalis*, *Tridax proculmbens*, are common and well adapted to the environmental conditions (Smith 1949; Kingdon 1989; Adkins, 2015).

Experimental designs and layout

Litter collection and quantification

Litter collection was carried out from 1 May 2008 to 30 April 2009; 10 transects of 200 m length, not less than 100 meters apart were traced through the forest. Forty (40) sample plots (4x4m, the area was overlaid with a plastic sheet) were established on each transect, these were marked with pegs painted red spray; the closest trees to the pegs were also marked with red spray paints as a reminder in case the pegs are removed. The fallen litter was collected on weekly bases; the collected litter was air dried and weighed and the quantity expressed as kg/ha/yr.

Leaves from standing biomass were also collected, air dried, weighed and put into monthly bags.

Litter decomposition and nutrient release

This experiment was carried out from 1 May 2008 to 30 October 2011. Freshly fallen litter was collected from the sites of litterfall experiments; the litter was air-dried and thoroughly mixed. Then, 75 composite samples were prepared for litterbags experiments. Litterbags of 30x30 cm with mesh size of 2 mm of Nylon fabric were used (Graca *et al.*, 2005). Each of the litterbags were filled with 250 g of litter and buried in the soil at depths of 15 – 30 cm. Sets of litterbags (25 samples) were withdrawn at intervals of 6, 12 and 18 months. After each collection, the nylon mesh bags were carefully brushed out and cleared of foreign materials (soil, roots, seeds and fauna). The withdrawn samples were reweighed and reanalyzed for the remaining matter and mineral content losses were deduced.

Soils description and sampling

The soils of the study site were characterized by field description and laboratory analysis. In the field, soil profiles were opened by digging 2 pits (1x1x1.5 m), they were described and samples taken for laboratory determinations. Five other samples were taken by soil auger from the corresponding horizons demarcated in the profiles; then the samples of the matching horizons were mixed up to form three 3 composite samples for their physical and chemical analysis.

Analysis of organic materials

Samples of live leaves, litterfall and decomposed litter were packed in labelled paper bags of 25 g each and delivered to the soil science laboratory, Faculty of Agriculture, University of Khartoum. The samples were air-dried, milled powder and subjected to wet digestion by heating in presence of conc. H_2SO_4, HNO_3 and $HClO_4$, then following parameters were analyzed: 1/ Nitrogen was determined by micro Kjeldahl method (Pearson 1970); 2/ Phosphorus was measured using spectrophotometer after ashing (Pearson, 1970); 3/ Potassium was determined by flame photometer (Chapman and Pratt, 1961); 4/ Calcium and magnesium were determined by atomic absorption spectrophotometry; 5/ Organic carbon was determined by Walkley and Black method (Walkley and Black, 1934) and the organic matter equalled organic carbon ×1.72.

Soil analysis

Samples of soil were packed in labelled paper bags of 500 g each and delivered to the soil science laboratory, University of Khartoum for analysis. Upon delivery to the laboratory, the soils were characterized for their general physical and chemical properties. Soil samples were air dried and sieved to 2 mm mesh size and the following parameters were determined: 1/ Particle size distribution was obtained by using the modified hydrometer method (Day, 1965) and the textural classes were assigned according to the American system (Soil Survey Staff, 1999); 2/ Bulk density was determined by the cylinder method; 3/ pH was measured by a pH meter equipped with a combined electrode in a soil paste (soil/water = 1:5); 4/ Electrical conductivity (EC) was measured by an EC meter in a water extract aliquot of the soils; 5/ Exchangeable elements were extracted by the international method using ammonium acetate, then Ca and Mg were determined by titration with versenate (Chapman and Pratt, 1961), Na and K were determined directly by using an EEC flame photometer on an appropriate dilute portion of the solution extracts; 6/ Nitrogen was determined by micro Kjeldahl method (Pearson, 1970); 7/ Phosphorus was determined by spectrophotometer using $NaHCO_3$ method (Chapman and Pratt, 1961); 8/ Organic carbon was determined by Walkley and Black method (Walkley and Black, 1934) and the organic matter equalled organic carbon ×1.72.

Statistical analysis

The data obtained from the different experiments were analyzed by a PC computer (Excel) and the temporal variation of litterfall and decomposition processes were represented by curves traced on an excel spread sheet.

RESULTS

Soil characterization

Soil profile description

The soil under teak plantation is red yellowish Oxisols (Soil Survey Staff, 1999), and the typical profile shows the following horizons and main features:

A_1 horizon: 0 – 20 cm deep; dark red coloured; sandy loam textured; crumb-aggregated structure, stable; porous; wet; small gravels; horizontal, varying sizes, coherent and stable concretions; tap and adventitious roots, dense big and small roots; few animals and insects are present; sharp and undulating at certain point boundary.

B horizon: 20 – 40 cm deep; yellow-red coloured; sandy clay textured; crumb-aggregated structure, stable; slightly prose fractal; wet; small gravels; horizontal, varying sizes, coherent and stable concretions; few roots; low biological activity; diffuse boundary.

C horizon: 40 – 60 cm deep; yellow-red coloured; sandy clay textured; aggregated structure, stable; slightly porous; wet; small gravels; small smooth concretions; nil roots; low biological activity; diffuse boundary.

Physical and chemical characterization of the soil

The particle size distribution of this soil shows that silt and clay contents are higher in the surface layer and variable in the deeper layers; while the sand content is lower in the surface layers and increases in the bottom layer (Table 1). The clay fraction in the subsurface and deeper horizons is higher by several folds than that of the corresponding sand (clay/sand = 1.7-3 folds) and silt (clay/silt = 2-2.6 folds) contents; yet the soil texture can be classified as clay loam to clay in subsurface (Soil Survey Staff, 1999). The soil has the same values of bulk density through out the profile and range at a medium category bulk density values. The soil reaction is acidic and pH values decrease in the deeper horizons. The soil electrical conductivity values are the same in all the horizons, amount to 0.3 dS/m denoting that the soil is not saline. The exchangeable Ca contents are about 7.4 Meq/100 g soil on the average and they decrease in the bottom layers. Magnesium contents are the same in all the layers and amount to 3.7 Meq/100 g soil on the mean. Potassium contents are below unity values in all the layers, they are unevenly distributed and range between 0.2 to 0.7 Meq/100 g soil. Mean while Na contents are about 3.7 Meq/100 g soil on the average and they decrease in the bottom layers of the profile. Organic carbon and organic matter contents are above unity values in the surface layer and they decrease in the subsurface horizons and with values less than unity. Nitrogen contents are below unity in all the horizons and the surface layer has higher values than the deeper ones; similarly, phosphorus contents are also below unity but they are evenly distributed within the profile. The C/N ratios in this soil are less than ten, denoting a higher turnover dynamic of the soil organic matter.

Assessment of litterfall

The temporal variation of litterfall in the teak plantations was characterized by weak steady increase during the period of the rainy season, the months August-September 2008 with monthly increment fall of 5 Kg/ha. As from September onwards, there was a very sharp progressive increase of litterfall that reached a peak at January 2009 and with monthly increment of 63.7 Kg/ha (Figure 1). This pattern was followed by a very sharp decrease of litterfall that reached nil value at March and April, and with monthly decease rate of 125 Kg/ha. On the other hand, the total litterfall input in this teak plantation ecosystem amounted to 1404.4 Kg/ha.

The organic carbon, calcium and magnesium contents in the litter of teak trees varied in a steady low rate during May-September 2008, and with monthly increments of 1.1, 0.6 and 0.1 Kg/ha, respectively (Figure 2). As from September onwards, there was a very high progressive increase of contents of organic carbon and calcium in particular in the litter that reached a peak in January 2009, and with monthly increments of 14.3, 10.6 and 2.4 Kg/ha for organic carbon, calcium and magnesium, respectively.

Table 1. Physical and chemical characteristics of soils in Yatta teak plantation forest in Western Equatoria State, South Sudan

Depth	Sand	Silt	Clay	Bulk density	pH	Ec	Ca*	Mg*	K*	Na*	O.C†	O.M‡	N	C/N	P
(cm)	(%)	(%)	(%)	(g/cm^3)		(dS/m)					(%)	(%)	(%)		(ppm)
0-20	22.7	41.3	35.9	1.5	5.5	0.3	8.7	3.7	0.4	5.0	1.9	3.2	0.25	7.6	0.40
20-40	18.0	27.0	55.0	1.4	5.4	0.3	7.4	3.7	0.7	3.7	0.9	1.5	0.13	6.9	0.39
40-60	29.9	19.9	50.2	1.4	4.4	0.3	6.2	3.7	0.2	2.5	0.7	0.7	0.11	6.4	0.39

*Units in Meq/100 g soil; †O.C: Organic Carbon; ‡O.M: Organic Matter.

As from January onwards, there was a strong decease in these nutrients contents in the litter to reach nil value in march-April and the monthly rate of respective decline 28.1 Kg/ha for organic carbon, 20 Kg/ha for calcium and 4.5 Kg/ha for magnesium. The pattern of temporal variation of these nutrients occurred in parallel pathways, organic carbon on the upper echelon followed closely by calcium and magnesium at lower level.

The temporal variation pattern of contents of nitrogen, potassium and phosphorus was characterized by steady weak increase from May to September 2008, with respective monthly increments of 0.08, 0.14 and 0.04 Kg/ha (Figure 3). As from September onwards, there was very strong increase in these nutrients contents, and they reached peak values of 7.8 Kg/ha for potassium in December 2008, and 7.5 Kg/ha for nitrogen and 4.9 Kg/ha for phosphorus in January 2009; the monthly increments of these nutrients contents in the specified periods were 1.3, 1.6 and 0.9 Kg/ha for nitrogen, potassium and phosphorus, respectively. There after, a rapid decline was observed in the contents of these nutrients, and with respective decline rates of 2.5 Kg/ha for nitrogen, 2 Kg/ha for potassium and 1.6 Kg/ha for phosphorus.

The total organic carbon input through litterfall from this teak plantation was estimated to amount to 335.7 Kg/ha which constitutes 23.9% of the total litterfall input. The inputs of the other nutrients were as follows in a descending order and with their percentage of the total litterfall shown between brackets, Ca: 216 (15.4%) Kg/ha; Mg: 54.7 (3.9%) Kg/ha; K: 32.9 (2.3%) Kg/ha; N: 32.2 (2.3%) Kg/ha and P: 14.7 (1.1%) Kg/ha.

A general pattern of litterfall, organic carbon and nutrients contents temporal variation was as follows, slow steady increase from May to September 2008 and a strong increase between September 2008 and January 2009 and then a sharp decline between January and March-April 2009.

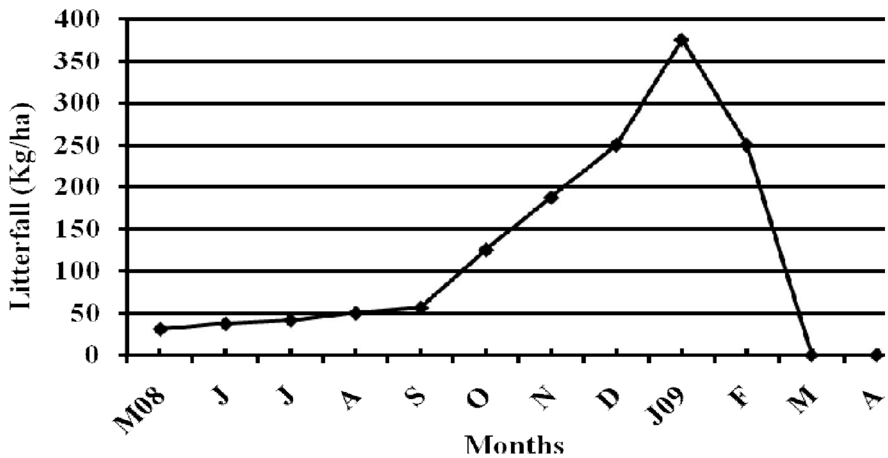

Figure 1: Temporal variation of litterfall in Yatta teak plantation forest in Western Equatoria State, South Sudan

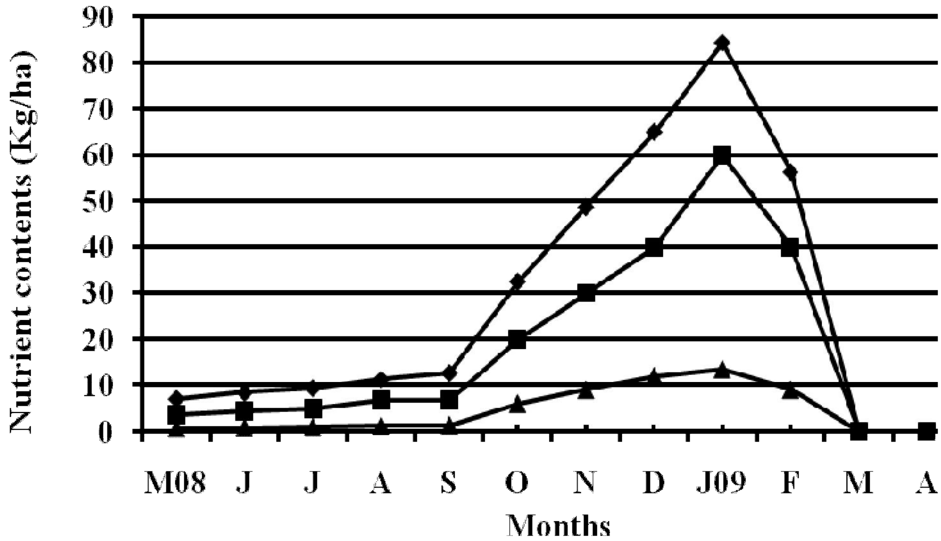

Figure 2: Temporal variation of organic Carbon (♦) Calcium (■) and Magnesium (▲) in litter of Yatta teak plantation forest in Western Equatoria State, South Sudan

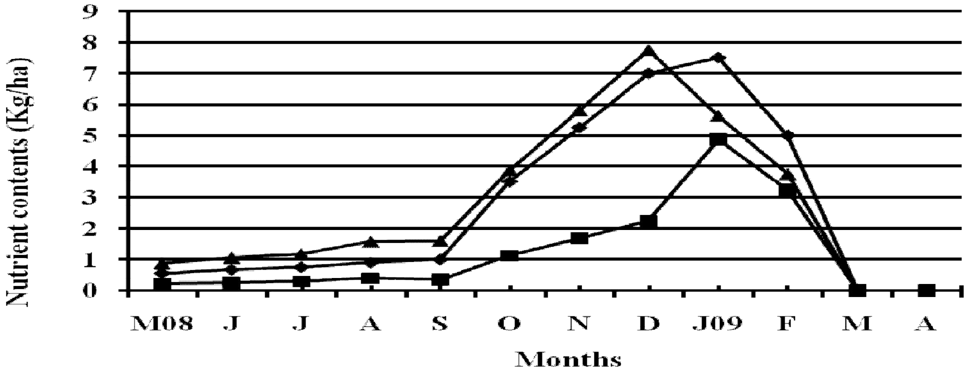

Figure 3: Temporal variation of Nitrogen (♦); Phosphorus (■) and Potassium (▲) in litter of Yatta teak plantation forest in Western Equatoria State, South Sudan

Assessment of litter decomposition and nutrient release

The litter decomposition of the teak plantation was characterized by very strong rate of organic matter loss, so that the reduction rates during the specified periods were, 52% at the end of six months, 82% at the end of twelve months and 95% at the end of 18 months period; hence the remaining weights, out of 250 g at the end of the selected periods were: 120 g at the end of six months, 45 g at the end of 12.5 g at the end of 18 months decomposition period (Figure 4).

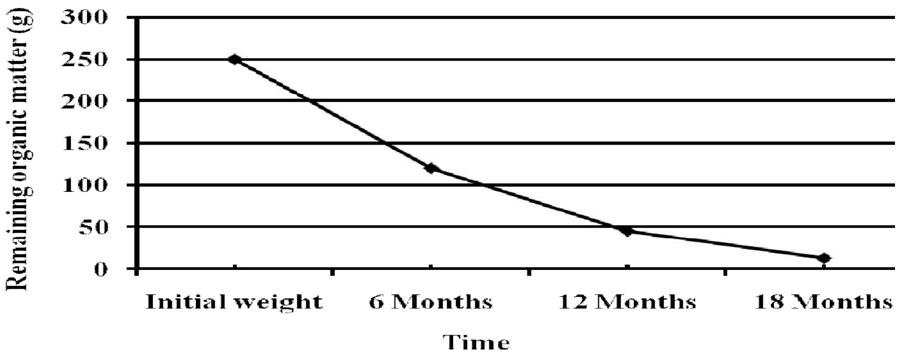

Figure 4: Remaining organic matter in litter of teak after undergoing decomposition process successively at 6, 12 and 18 months periods in Yatta teak plantation forest in Western Equatoria State, South Sudan

The decomposition rate of the teak plantation litter was very active and strong. By the end of six months decomposition period, about 90% of calcium, potassium and phosphorus were lost from the initial quantity of organic mater used (Figures 5 and 6); the corresponding losses of organic carbon and magnesium were 70 or above, however, nitrogen showed moderate rate of release of only 23.2%. The nutrients losses continued with stronger rate during the 12 months period of decomposition and more than 95% of Ca, P and K were lost; the corresponding release rates of organic carbon, Mg and N were, 94.1%, 86.3% and 78.4%, respectively. By the end of 18 months decomposition period more than 96% of the nutrients were released from organic matter used. Quantity wise, the remaining matter from these nutrients was less than a unity gram, or even only traces for some nutrients like P and K.

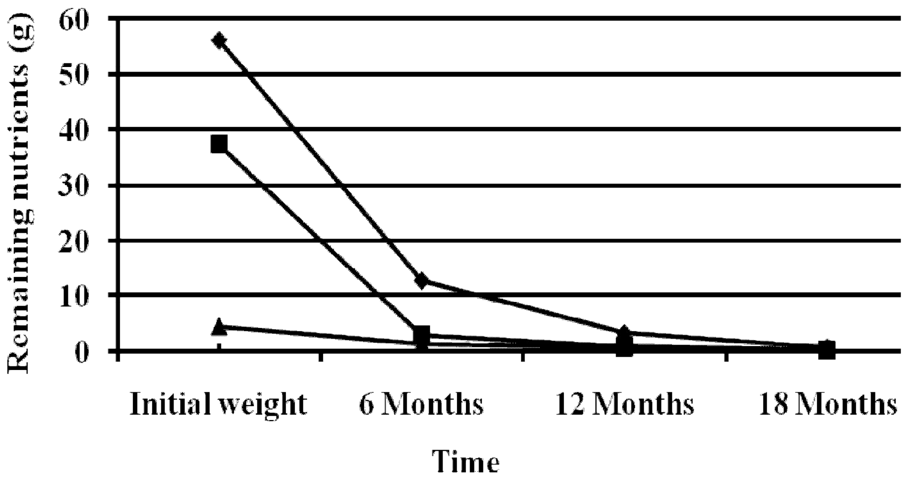

Figure 5: Remaining organic Carbon (♦); Calcium (■) and Magnesium (▲) in litter of teak after undergoing decomposition process successively at 6, 12 and 18 months periods in Yatta teak plantation forest in Western Equatoria State, South Sudan

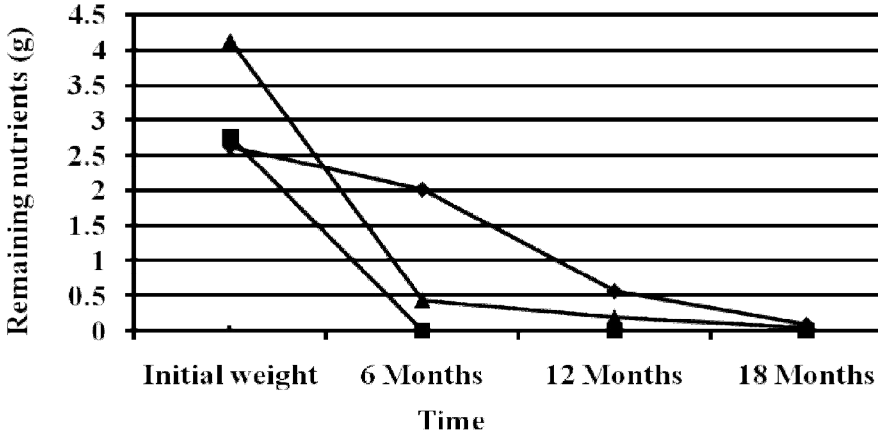

Figure 6: Remaining organic Nitrogen (♦); Phosphorus (■) and Potassium (▲) in litter of teak after undergoing decomposition process successively at 6, 12 and 18 months periods in Yatta teak plantation forest in Western Equatoria State, South Sudan

DICUSSION

Soils under this humid tropical plantation forest of *Tectona grandis* are Oxisolls with typical characteristics. They are deep, red yellowish, well textured and structured presenting free drainage. They are rich in organic matter and plentifully furnished with basic cations, nitrogen and phosphorus; and they have very low C/N ratio. They are slightly acidic and non-saline. Thus, these are very fertile soils. Nevertheless, this fertility is yet bound to the presence of the tree/forest cover that keeps this fertility within the ecosystem by the mechanism of the biogeochemical cycling of elements. For once the tree/forest stands are removed the soil will rapidly lose its fertility through massive decomposition of soil organic matter and leaching of the nutrients released (Duchaufour, 1984; Vitousek, 19984; Zheng *et al.*, 2006). Agroforestry is the most appropriate utilization type for exploiting these sites, whereby securing adequate output of crops and conserving their fertility rationally (Vergara and Briones, 1987; Schroth and Sinclair, 2003).

Litterfall in this forest is greatly influenced by seasonality. The fall is steady around 50 kg/ha during May-September within the rainy season;

very strong during September-February reaching a peak of 375 kg/ha in January coinciding with dry period and total foliage shedding of the stand; and nil fall during March-April at the onset of the new foliage of the stand. So this seasonality is directly linked to the pattern of moisture availability or stress induced by the rainfall regime (Parsons *et al.*, 2014) and the deciduous behaviour of the tree species. The total amount of litter input in this forest is 1404.4 Kg/ha; this is less than that in the corresponding broad-leave plantations in comparable sites (Dantas and Phillipson, 1989; Seta *et al.*, 2018). The quality of litter of this plantation is reflected in the higher amounts elements, organic C, N, P and basic cations; this indicates in other terms the richness of the site quality (Vitousek, 19984; Vitousek *et al.*, 1995; Ngaiwi *et al.*, 2018).

Litter decomposition in this forest is very rapid so that more than 52% of dry matter was lost during 6 months and amounted to 95% at 18 months period. Likewise the elemental lost was even more rapid so that more than 70% of most of them were lost during 6 months; with exception of nitrogen which least lost at a rate of 23%. Further more, by the end of 18 months period more than 96% of the elements studied were dissipated away, but even the lost of phosphorus reached ~100%. Conducive decomposing conditions of climatic (mesothermic temperature and optimal humidity); edaphic (ambient medium due to good texture and structure); high quality of litter (rich in organic C and N, P and basic cations); very high biological activity (soil microflora and myriad of fauna) lead to rapid consumption of dry matter and release of elements (Swift *et al.*, 1979; Songwe *et al.*, 1995; Isaac and Nair, 2005; Xiaogai *et al.*, 2013; Krishna and Mohan, 2017; Giweta, 2020).

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سقوط نثار، تحلل و تحرير عناصر غذائية في غابة تيك في ولاية غرب الإستوائية،جنوب السودان*

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مستخلص البحث: هذه الدراسة قيمت إنتاج النثار في غابة تيك، و شخصت ترب، تحلل نثار و تحرير عناصر غذائية في غاية ياتا، ولاية غرب الإستوائية، جنوب السودان؛ في خلال الفترة مايو 2008 و أكتوبر 2011.النثار الساقط قد جمع أسبوعياً من مرابيع مساحتها 16 م^2 موزعة تحت الغابة و بعشرة مكررات. و قد أستعملت خمسة و سبعين من أكياس النثار لتقيم تحلله و تحرير العناصر، و دفنت هذه الأكياس في التربة الي أعماق 15 و 30 سم؛ و تم سحب 25 كيس في آماد من 6 و 12 و 18شهراً . التربة هي من نوع الأوكسيسول، طيني طمي الي طيني، غني بالمادة العضوية، و مغذي بوفرة من العناصر الغذائية. بلغ إنتاج النثار 1404 كجم/هك/سنة و مع إنتاج أقصي و أدني في الشهور الجافة و الرطبة علي التوالي. فقدان المادة الجافة كانت عالية و بلغت مداها ما بين 52% الي 95% في خلال فترة الإختبار. العناصر C، K، N، P، Ca و Mg قد حررت بسرعة و بمعدلات علي التوالي: 77.2%-98.7%، 89.5%-98.8%، 23.2%-96.3%، 99.8%-100%، 92%-99.3% و 70%-96.3% في خلال فترة الإختبار. أظهرت النتئج مقدرة خصوبة عالية لموقع غراس غابة التيك و التي يمكن أن يدعم نمو مستدام لمخزون الغراس.

كلمات مفتاح: غراس شجرة التيك؛ تشخيص تربة؛ سقوط النثار و تحلله؛ عناصر محررة.

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