Nigerian Journal of Soil Science

Journal homepage:www.soilsjournalnigeria.com

Decomposition of *Entandrophragma cylindricum* Tree Prunings in Agroforestry System in Onne, Rivers State

Koyejo, A.O. [1] Koyejo, O.A.[2] Olatidoye, O.R.[2] and Adetunji, A.S.[3]

1. Forestry Research Institute of Nigeria, Humid Research Station, Umuahia.
2 Forestry Research Institute of Nigeria, Ibadan
3 Forestry Research Institute of Nigeria, Rainforest Research Station, Ore.

ARTICLE INFO

Article history:
Received January 20, 2021
Received in revised form May 28, 2021
Accepted June 18, 2021
Available online July 20, 2021

Keywords:
Decomposition
Etandrophragma cylindricum
Placement methods
Turnover coefficients

Corresponding Author's E-mail Address:
afoblackk@yahoo.com

https://doi.org/10.36265.njss.2021.310211
ISSN– Online **2736-1411**
Print **2736-142X**

ABSTRACT

A study was conducted at Swamp Forest Research Station, Onne, Forestry Research Institute of Nigeria, to evaluate the rate of decomposition of *E. cylindricum* tree prunings. The experiment was a 2x8 factorial in a randomized complete block design with three replications. The first factor comprises two placement methods (surface-placed and soil-incorporated) and the second factor comprises eight biweekly sampling intervals (2 – 16 weeks). The litterbag technique was employed. Results indicated that the Total leaf decomposition (100.0%) of soil incorporated leaf litter was obtained at 16th week after litter placement (WALP). Soil-surface placed had 98.00% at 16th WALP. Leaf half-lives of the soil-surface placed and soil incorporated were 5.08 and 2.10 WALP respectively. The turnover coefficients (k_1) of the soil surface-placed and soil -incorporated leaf litter of *E. cylindricum* were 6.93yr^{-1} and 17.33 yr^{-1} respectively. The high rate of fresh leaf decomposition and subsequent release of nutrient make *E. cylindricum*leaf pruning a good source of organic manure for soil fertility restoration

1.0 Introduction

Decompositionis a sequential process that results in the breakdown of complex organic compounds by decomposers into simpler substances, releasing nutrients as by-product (Saha *et al.*, 2016; Yadav and Malanson, 2007). Itis an important channel for organic matter and energy into the soil and is necessary for nutrient cycling in ecosystem (Triadiati*et al.*, 2011). In terrestrial ecosystem, decomposition plays an important role in turnover of nutrient and maintenance of soil fertility and productivity (Saha *et al.*, 2016).Maintenance of fertility in any given soil system such as the agroforest is achieved by the high and rapid process of litter decomposition (Chandraa*et al.*, 2015).
Litter decomposition is therefore a crucial ecosystem process that defines and maintains the plant-soil relationships by regulating the nutrient turnover and the build-up of soil organic matter. In fact, the release of nutrients through decomposition is the main source of available nutrients for plants in most unmanaged terrestrial ecosystems (Chandraa*et al.*, 2015). A thorough understanding of litter decomposition is essential in understanding the functioning of agroforestry ecosystems, since it is central to many ecosystem functions such as soil formation and nutrient cycling (Rawat *et al.*, 2010; Yu *et al.*, 2004).The rate of litter decomposition is regulated by many factors such as prevailing climatic variables, substrate quality and activity levels of decomposers' community (Kuruvilla *et al.*, 2014; Pandey *et al.*, 2007; Karberg *et al.*, 2008; Zheng *et al.*, 2006). Climate and substrate quality are the two most important factors in determining the leaf decomposition rate

(Bisht *et al.*, 2014: Rawat *et al.*, 2010). Moisture and temperature are the vital variables of climate that affects decomposition., they affect both the development of plant cover and the activities of microorganism which are highly critical factors in soil formation (Krishna and Mohan, 2017; Salahab and Scholes, 2011.).

Substrate quality could be referred to as the inherent chemical and structural features of the leaf that guide the activity of decomposer organisms, which partially regulate the rate of decomposition (Karberg *et al.*, 2008; Zheng *et al*., 2006). Substrate quality has been related to the nitrogen concentration (N), the lignin content and the C:N ratio (Seta *et al*., 2016; Abugre*et al.*, 2011; Tripathi *et al*., 2009). High initial concentrations of nitrogen (N) or phosphorus (P) in litter increases decomposition rates. Unlike nitrogen and phosphorus, a high initial lignin concentration retards the decomposition process (Dhanya *et al*., 2013). Investigations have revealed that initial N and P have a positive correlation with leaf litter weight loss (Bargali*et al.* 2015). Leaf litter with high concentration of phenolic (tannin and lignin) compounds and low concentration of nitrogen decomposes slowly (Zhanq*et al*., 2008). *Entandrophragmacylindricum* is a deciduous and dioecious large tree attaining a height of 55 – 65 meters tall (The Plant List, 2013). It belongs to the Meliaceae family also known as mahogany. It is commonly known as Sapele, one of Nigeria's largest and finest trees producing the popularly known Sapele wood (Keay, 1989). It is one of the highly ranked export timbers of tropical Africa (Lourmas*et al* 2007). Due to its high commercial importance, *E. cylidricum* has been subjected to over exploitation and is now listed in IUCN Red List as vulnerable (Kemeuze, 2008). Introducing *E. cylindricum* into our farming system through agroforestry will not only help in alleviating the problem of over-exploitation but also in maintaining soil fertility through the decomposition of its litter and tree prunings.

The objective of this study was to evaluate the rate of decomposition of *Entandrophragmacylindricum*tree prunings over time.

2.0. Materials and methods

2.1 Study Area

The study took place at the Nursery Unit of the Swamp Forest Research Station, Forestry Research Institute of Nigeria, Onne, Rivers State, Nigeria. Onne is a village located about 7km off Port Harcourt, Rivers State capital. It lies on latitude 4° 51 N and longitude 0 7° 03 E with an elevation of 40meters above sea level (Anegbeh, 1997).

The climate is characterized by long wet season and short dry season. The wet season starts from April and ends in October while the dry season starts from November and ends in March (Anegbeh, 1997). Jagap*et. al.,* (1999) reported that the climate of the area is typical of the humid rainforest. The mean annual rainfall is 2,400mm in a mon-omodal distribution falling in one season (March - November). Temperature varies from 28°C in February and March (warmest months) to 25°C in July (coolest month). Relative humidity varies from 70% in February (driest month) to 84% in July (rainy month) (Anegbeh, 1997). Sunshine also varies from 2 hours per day (September) to 6 hours per day (February) (Anegbeh, 1997).

2.2 Leaf Litter Decomposition study

The experimental design was a 2x8 factorial experiment in a randomized complete block design (RCBD) with three replications, it was undertaken from July 2015 to November, 2015 (16 weeks).

The first factor comprises two placement methods (surface -placed and soil-incorporated) and the second factor comprises eight biweekly sampling intervals. The litter bag technique (Swift and Anderson, 1989) was utilized. 165 (one hundred and sixty-five) litter bags measuring 15cm x 20cm x 2cm were used, in each litter bag, 1g leaf litter of *E. cylindricum* was placed in the plastic mesh litter bag. Fifty-five (55), 25cm x 20cm polythene pots per block were filled with 4kg topsoil obtained from the teak plantation at FRIN, Onne.

In the surface-placed method the litterbag with 1g leaf litter was placed on top of each of the filled poly pots, while in the soil-incorporated method, the poly pots were initially filled with 2kg topsoil collected from the teak plantation. In each of the 2kg filled poly bag, the litter bag containing 1g leaf litter was placed on top and covered with another 2kg topsoil. The poly pots were adequately watered, when there was no rain. Weeding of the pots and the study site was done fortnightly.

Fifty-five of the poly pots containing the litterbag in each of the methods were placed per block. Three litter bags from each block in each method were sampled at the following bi-weekly sampling periods: 2, 4, 6, 8, 10, 12, 14, and 16 WALP. The harvested litterbags were washed with water to remove soil particles, fine roots and living organisms adhering on leaf. The washed leaf litterbags were sun – dried and later oven – dried in small paper bags at 70^0C for 48hrs. at the Laboratory of the Department of Forestry and Environmental Management, College of Natural Resources and Environmental Management, Michael Okpara University of Agriculture, Umudike, Nigeria. The oven dried leaf litter was weighed and the loss in weight recorded for further statistical analysis.

2.3 Computational Procedures for Fresh Leaf Decomposition Studies

The data collected were used for the following computational procedures.

2.4 Cumulative Fresh Leaf Decomposition (%) per Sampling Interval

At each sampling period, Okeke and Omaliko's (1992) computational method was used to determine the cumulative fresh leaf decomposition rate (%) as follows.

$$D(\%) = \frac{a - b}{a} \times 100$$

where:

D = Cumulative fresh leaf decomposition weight loss (%)

a = Initial weight at the beginning of the experiment

b = Present weight at the sampling interval

2.5 Fresh leaf half-life and full-life estimations

Okeke and Omaliko's (1992) method was employed to calculate the estimated fresh leaf half-life and full life (time of 50% and 100% fresh leaf decomposition) of the soil surface-placed and the soil-incorporated fresh leaf of *E. cylindricum*. Here, a simple linear regression equation, $Y = a + bx$ was computed, using the various sampling intervals (X) and the cumulative fresh leaf decomposition percentages overtime (Y). The mean cumulative percentage losses in dry weight over time were used along with the predicted values obtained from simple linear regression equation to calculate the fresh leaf half-lives and full-lives (total decomposition rates) of both modes of fresh leaf decomposition studies. From the regression equation, Chi-square (X^2) at $P \leq 0.05$ was obtained for each mode of study. It was also used to determine the goodness of fit of both expected and observed decomposition values.

2.6 Turnover coefficient (Tc)

Olson's (1963) equation and leaf litter half-life procedure of Okeke and Omaliko (1992) were used to compute the turnover coefficients of each mode of fresh leaf decomposition rates of *E. cylindricum*. Olson's (1963) equation is as follows:

$$k_1 = t_{1/2}\,(0.693)$$

where:
k_1 = leaf turnover coefficient
$t_{1/2}$ = leaf half-life overtime (either weeks, months or years)

2.7 Relative fresh leaf disappearance/decay rates (% day^{-1} sampling interval^{-1})

Relative fresh leaf disappearance/decay rate (% day^{-1} sampling interval^{-1}) was computed according to the procedures of Satchell (1974) and Okeke and Omaliko (1992) as follows:

$$r = \frac{a - b}{t}$$

where:
r = relative fresh leaf decomposition/decay (% day^{-1} sampling interval^{-1})
a = cumulative fresh leaf decomposition percentage at the previous sampling interval,
b = cumulative fresh leaf decomposition percentage at the present sampling interval,
t = time (number of days) between the present and the previous sampling intervals

2.8 Statistical analysis

The data obtained from the leaf decomposition study were statistically analysed using Fisher's Least Significant Difference (F-LSD) at $P \leq 0.05$ to determine significant difference between treatment means according to the procedures of Steel and Torrie (1980) and Alika (2006).Simple regression analysis was used to determine the relationships between the rate of decomposition and time.

3.0 Results

***3.1** Cumulative fresh leaf decomposition rate of E. cylindricum*

Table 1 shows the cumulative fresh leaf decomposition rates (%) overtime of *E. cylindricum* in two placement methods. In terms of Factor Time, the 14th and 16th WALP gave significantly the highest leaf decomposition percentages 86.17% and 99.00% respectively while the 2nd WALP had the least ($p<0.05$) value (39.17%). The results show that leaf decomposition rates increased significantly overtime. The summary of the results are stated significantly in the following order: 16 > 14> 12> 10> 8> 6> 4> 2> WALP.

Table 1 further shows that soil incorporated fresh leaf of *E. cylindricum* had significantly higher decomposition percentage (83.88%) than soil surface-placed fresh leaf decomposition value (67.30%). In terms of Time x Leaf placement methods (T x L) treatment interaction, the statistically similar fresh leaf decomposition values of soil incorporated leaf placement in 10th, 12th, 14th, and 16th, WALP (weeks after leaf placement) had significantly higher decomposition percentages than soil incorporated leaf placement method between 2nd and 8th WAP as well as soil surface-placed method between 2nd – 16th WALP. The least ($p\leq0.05$) result was obtained in the 2nd WALP of the soil surface-placed fresh leaf method.

Table 1: Cumulative mean fresh leaf decomposition (% overtime) of *E. cylindricum* in two different placement methods at Onne, Rivers State, Nigeria.

Leaf decomposition			
Time (T) (Weeks)	Leaf placement method (L) Soil -surfaced placed	Soil incorporated	Mean
2	33.67	44.67	39.17
4	47.67	55.33	51.50
6	56.00	83.33	71.33
8	63.67	92.00	76.17
10	70.33	97.33	83.83
12	77.33	100.00	88.67
14	92.33	100.00	96.17
16	98.00	100.00	99.00
Mean	67.38	84.08	
	F-LSD (0.05)		
Time (Week) {T}	2.94		
Leaf Placement methods {L}	1.39		
Interaction T x L	3.94		

Students t-test, however, indicated no significant difference between leaf litter decomposition and the fresh leaf decomposition (t- cal = 1.09 < t- tab =2.13).

The general trend shows that overtime fresh leaf decomposition in each of the placement methods increased signifi-

Table 2: Relative leaf disappearances/decay rates over time for the fresh leaf of *E. cylindricum* placed on the soil surface and incorporated into the soil

Relative fresh leaf disappearance (% day^{-1})			
Time (T) (Weeks)	Leaf placement methods (L) Soil-surface placed	Soil incorporated	Mean
2	2.40	3.19	2.80
4	1.00	1.14	1.07
6	1.12	1.88	1.50
8	0.55	0.74	0.65
10	0.48	0.38	0.43
12	0.49	0.19	0.34
14	1.07	0.00	0.54
16	0.40	0.00	0.20
Mean	0.94	0.94	
	F-LSD (0.05)		
Time (Week) {T}	0.47		
Leaf Placementt Methods {L}	NS		
Interaction T x L	0.67		

cantly. However, soil incorporated fresh leaf had higher decomposition rate overtime than soil surface-placed.

3.2 Relative fresh leaf disappearance rate

Table 2 summaries relative fresh leaf disappearance/decay rate over time for fresh leaf of *E. cylindricum* in two placement methods. In terms of factor time, the 2nd and 16th WALP had significantly the highest and least relative decay rates. The statistically similar leaf decay rates of the 4th and 2nd WALP were statistically higher than those of the 10th – 16th WALP. Generally, fresh leaf relative decay rates decrease over time.

There were no significant differences between the relative decay rates of soil surface-placed and soil-incorporated methods of fresh leaf of *E. cylindricum*.

3.3 Turnover coefficients (k_1), fresh leaf half-lives and full-Lives of E. cylindricumfresh leaf in two modes of leaf placement.

Table 3 shows that the turnover coefficients (k_1) of the soil surface-placed and soil-incorporated fresh leaf of *E. cylindricum* were 6.93 and 17.33 respectively. The table further shows that the half-lives of the leaf placement modes were approximately 5 and 2 weeks for soil surface-placed and soil-incorporated respectively. The full lives of *E. cylindricum* fresh leaf decomposition was approximately 16 and 11 weeks for soil surface-placed and soil-incorporated leaf placement methods respectively.

The regression equation function, Y═ a + bx, showed a good fit for both modes of litter decomposition (Table 4). The observed and expected leaf decomposition percent-

Table 3: Turnover coefficients (k_1), fresh leaf half-lives ($t_{1/2}$) and full-lives ($t_{1.0}$) of *E. cylindricum* in two modes of fresh leaf placement methods

Mode of Litter Placement	K_1 (average yr^{-1})	Half-life ($t_{1/2}$)		Full-life ($t_{1.0}$)	
		Week	Year	Week	Year
Soil surface	6.93	5.08	0.10	16.36	0.31
Soil incorporate	17.33	2.10	0.04	10.61	0.20

Table 4: Regression equation parameters, overall relative fresh leaf rates, observed and expected losses (% decomposition) in dry weight of *E. cylindricum* fresh leaf in two fresh leaf placement methods

	% Decomposition Observed	Expected	Expected time for 100% loss	Regression equation Parameters Slope	Intercept	Correlation
	16thWk	16thWk		(b)	(a)	(r)
soil surfaces	98.00	98.39	16.36 wks	4.43	27.50	0.9942
	(0.88% dy^{-1}) x	(0.88% dy^{-1}) x	(0.87% dy^{-1}) x			
Soil incorporated	100.00	111.83	13.02 wks	3.96	48.40	0.8840
	(0.89% dy^{-1}) x	(1.00% dy^{-1}) x	(1.10% dy^{-1}) x			

x ═ overall relative decay rate for stated periods

ages for both modes at the end of the studies (16th WALP) are shown in Table 4. The relative decay rates for the observed and expected were the same (0.88% dy^{-1}) for soil surface-placed leaf placement modes at the 16th WALP. The observed relative leaf decay rates of the soil-incorporated leaf at the 16th WALP (0.89%) were similar to the expected value at the time of an expected 100% weight loss (1.10%).

4.0 Discussion

***4.1** Cumulative fresh leaf decomposition rate of E. cylindricum*

The cumulative mean fresh leaf decomposition of *E. cylindricum* of 47.7% (surface-placed) and 55.33% (soil-incorporated) at 4 WALP is higher than that of Hartemink and Sullivan (2001) in Papua New Guinea who observed 30.00% decomposition of leaf litter of *Piper aduncum* and *Gliricidiasepium* after 4 weeks. The difference between the decomposition rate of *Piper aduncum*, *Gliricidiasepium*and *E. cylindricum*is more of climate than litter quality. *Piper aduncum* and *Gliricidiasepium*are species with low C:N ratio (Hartemink and Sullivan 2001). Climate exercise strong influence over rate of litter decomposition. Generally,cold climate like that in Papua New Guinea results in low litter decomposition.Decomposers are more active under high temperatures and high relative humidity(Zhanq*et al*., 2008; Bisht *et al.*, 2014). The 98.00% cumulative decomposition of the soil surface-placed of *E. cylindricum* fresh leaf at the end of the study are in line with the results of Okeke and Leria (2005) for *Treculiaafricana's* soil surface-placed leaf litter (96.7%) and of Ekpendu (2003) for *Irvingiawombulu's* soil surface-placed leaf litter (97.2%). Total (100%) decomposition rates at the 12th WALP for soil-incorporated fresh leaf of *E. cylindricum* are higher than those of soil- incorporated leaf litters of *Grewia optiva* and *Populus*spp that had total decomposition in 9 and 17 months respectively (Kaushal and Verma, 2003). The difference between the decomposition rates of *E. cylindricum* and the species cited above could be as a result of the litter qualities of the plant species and different climatic conditions. Climate and litter quality are the two most important factors in determining the litter decomposition rate (Rawat *et al.*, 2010Bisht *et al.*, 2014). The influence of climate and litter quality in controlling litter decomposition rate varies across ecosystem types (Zhanq*et al*., 2008). Bisht *et al.*, (2014) The differential cumulative decomposition rates of soil surface-placed and soil-incorporated are in line with those of Kaushal and Verma (2003) they reported significant differences between soil surface-placed and soil-incorporated leaf litters of different agroforestry tree species in India. The faster decomposition rate of soil incorporated fresh leaf than surface placed could be as a result of favourable moisture condition, It has been reported that 90% of the effect of residue location/placement method ondecomposition is explained by mulch water content and that other limiting factors for decomposition such as soil–residue contact, N availability or microbial colonization are of minor importance compared to the water regime (Coppens *et al.*, 2007). Since *E. cylindricum* fresh leaf has high decomposition rates there is need for it to be utilized in traditional farming systems including home gardens in the tropics as organic manure/mulch. This will help to improve soil fertility in farmlands as well as improve trees and arable crop growth and yield in agroforestry systems.

***4.2** Relative decay/ disappearance rates*

The initial rapid relative disappearance/decay rates observed in the fresh leaf within the first 4 WALP irrespective of placement methods are in line with the reports of Abugre (2011) and Kaushal and Verma (2003). The rapid, initial phase of fresh leaf relative disappearance rates could be due to breakdown of small soluble carbon molecules, like starches, sugars and amino acids, remaining the more recalcitrant molecules like lignin, cellulose, fat and waxes. Decomposition during the initial stage is fast because these substances are easy to breakdown and are energy-rich. The second stage of decomposition, which is the breakdown of lignin, is not as fast as the first stage because of the presence of lignin which has complex and large molecules (Hasanuzzaman and Hossain, 2014; Abugre*et al.*, 2011; Matos *et al* 2011).

The non-significant differences between the relative decay rates of the two modes of placement for fresh leaf decomposition indicate similarity in daily decay processes throughout the study period. This feature further stresses that the fresh leaf of the species could be used as mulch materials for weed control and for soil conservation.

***4.3** Turnover Coefficients, Half-Lives And Full-Lives Of E. cylindricum*

Fresh Leaf

The predicted half-lives and full lives obtained for fresh leaf for the two placement methods (5.08/2.10 and 16.36/10.61) of *E. cylindricum* are within the range for trees/shrubs in the tropics. Bockheim *et. al.* (1991) reported that there is wide variability in litter half-lives of species of different climatic regions from arctic to tropical climates. The predicted half-life of 5.08 weeks for soil surface-placed fresh leaf of *E. cylindricum* is in line with the result of Ekpendu (2003) for soil incorporated leaf litter of *Irvingiawombulu* (5.9 weeks) and Hartemink and Sullivan (2001) for leaf litter of *Piper aduncum* (7 weeks). The predicted half-life of 2.10 weeks for soil incorporated of the fresh leaf of *E. cylindricum* is lower than those obtained in the studies cited above. However, the results of *E. cylindricum* half-lives for the fresh leaf is in contrast with those of Dhanya *et al.*, (2013) for *F. benghalensis* (5.54 months) Moro and Domingo (2000) for *Pinus* species (4 – 5 years), for *Cistus*spp (3.2 years) and *Adenocarpus*spp (1.3 years). Differences between the half-lives of *E. cylindricum* and those of *F. benghalensis,Pinus, Cistus* and *Adenocarpus spp* might be due to differences between the nutrient contents of these species. Coniferous litter is known to be rich in recalcitrant compounds. The half-lives of fresh leaf decomposition rates of *E. cylindricum* once again indicate that fresh leaves of the species could be useful as an organic manure for fast-growing arable crops in the field. Such crops will maximally obtain nutrients from the decomposing *E. cylindricum* fresh leaf pruning and leaf litter for their initial enhanced vegetative growth rates.

5.0 Conclusion

The study has revealed that *E. cylindricum* tree pruning has a high decomposition rate. The fresh leaf decomposed to half of its original mass in 5 weeks for surface-placed and 2 weeks for soil-incorporated. Total decomposition of 16 weeks for soil surface-placed and 11 weeks for soil-incorporated indicate the total release of the nutrient elements in the leaf. The decomposition constants of 6.93 yr^{-1} and 17.33 yr^{-1} revealed that nutrients in the fresh leaf could be released into the soil within a year. The tree pruning could be used as an organic manure for soil fertility restoration.

The comparatively high relative decay rate of the fresh leaf and the subsequent release of nutrient elements to the soil are vital for sustenance of forest plantations and fast-growing arable crops when incorporated in an agroforestry system. Hence, conservation strategies that introduces *E. cylindricum* into agricultural lands will not only help in preserving the tree species but also in sustaining the land for increased productivity.

Tree pruning of *E. cylindricum* could be used as mulch for weed and soil erosion control since its half-life and full-life are enough periods for weed control and reduction of soil erosion in the farming system. Mulching reduces the soil temperature, resulting in an improved buildup of soil fauna that helps crop productivity These qualities of *E.cylindricum* fresh leaf makes it suitable for adoption as an agroforestry species in humid rain forests of Nigeria.

References

Abugre, S, Oti-Boateng, C and Yeboah, M. F. (2011). Litterfall and decomposition trend of *Jatropha curcas*L. leaves mulches under two environmental conditions. *Agriculture and Biology Journal of North America* 2(3):462-470

Alika, J. E (2006). *Statistical and Research Methods* 2nd Edition Ambik Press, Benin City, Nigeria, viii + 366pp.

Anegbeh, P.O. (1997). Evaluation of selected woody species for agroforestry system on acid soils of Onne southern Nigeria. Unpublished Ph.D Thesis. Department of Crop Science and Forestry, Rivers State University of Science and Technology.

Bargali, S. S., Shula, K., Singh, L., Ghosh, L and Lakhera. M. L. (2015). Leaf litter decomposition and nutrient dynamics in four tree species of dry deciduous forest. *Tropical Ecology* 56: 191-200.

Bisht, V. K., Nautiyal, B. P., Kuniyal, C. P., Prasad, P and Sundriyal, R. C. (2014). Litter Production, Decomposition, and Nutrient Release in Subalpine Forest Communities of the Northwest Himalaya. *Journal of Ecosystems*, 2014: 13pp

Bockheim, J. G., Jensen, E. A., Heisey, D. M. (1991). Nutrientdynamics in decomposing leaf litter of four treespecies on a sandy soil in Northwestern Wisconsin. *Canadian Journal of Forestry Research* 21:803-812.

Chandraa, L.R., Raia, A, Pandeb, V and Singha, N. (2015). Litter decomposition and nutrient cycling in temperate forest of Kumaun region. *International Journal of Fundamental Applied Science,* 4, (4): 91-98.

Coppens,F., Garnier, P., Findeling, A Merckxb, R., Recous, S. (2007). Decomposition of mulched versus incorporated crop residues: Modelling with PASTIS clarifies interactions between residue quality and location. *Soil Biology and Biochemistry* 39 (2007) 2339–2350.

Dhanya, B. Viswanath, S and Purushothaman, S. (2013). Decomposition and Nutrient Release Dynamics of Ficus benghalensis L. Litter in Traditional Agroforestry Systems of Karnataka, Southern India. ISRN Forestry (2013): 7pp

Ekpendu, O (2003). Litter production and nutrient cycling in an *Irvingiawombulu*/cocoyam-based agroforestry ecosystem. Unpublished M.Sc thesis of the Department of Forestry and Environmental Science, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria 114pp.

Hartemink, A. E and Sullivan, J. N. O. (2001). Leaf litter decomposition of *Piper aduncum, Gliricidiasepium and Imperata cylindrica* in the humid lowlands of Papua, New Guinea. *Plant and Soil*, 230 (1):115-124.

Hasanuzzaman, M, Mahmood, H. (2014) Leaf Litter Decomposition and Nutrient Dynamics Associated with Common Horticultural Cropland Agroforest Tree Species of Bangladesh. International Journal of Forestry Research. DOI./10.1155/2014/805940. Available at https://www.hindawi.com/journals/ijfr/2014/805940/

Hossain, M., Siddique, M. R. H., Rahman, M. S., M. Z. Hossain, M. Z. and Hasan, M. M (2011). Nutrient dynamics associated with leaf litter decomposition of three agroforestry tree species (*Azadirachta indica, Dalbergia sissoo, and Melia azedarach*) of Bangladesh," *Journal of Forestry Research*, 22, (4): 577–582.

Jagap, S. S., Alabi, R. T., Robert, A. B. C and Adeleye, O (1999). Weather bulletin. International Institute of Tropical Agriculture, 90pp.

Karberg, N. J., Scott, N. A. and Giardina C.P. (2008) Methods for estimating litter decomposition. In: Hoover C.M. (eds) *Field measurements for forest carbon monitoring*. Springer, Dordrecht. 103 – 111.

Kaushal, R and Verma, K. S (2003). Leaf litter decomposition in different agroforestry tree species as influenced by climatic variables and substrate quality. A paper submitted to the XII World Forestry Congress, Quebec City, Canada. Available at http://www.fao.org/3/XII/0464-B5.htm

Keay, R. W. J. (1989). Trees of Nigeria. Stanfield. Clarendon Press, Oxford, United Kingdom. 476 pp.

Kemeuze, V. A., 2008. *Entandrophragma cylindricum* (Sprague) Sprague. In: Louppe, D., Oteng-Amoako, A.A. & Brink, M. (Eds). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique-tropicale), Wageningen, Netherlands. Available at https://uses.plantnet-project.org/en/Entandrophragma_cylindricum_(PROTA)

Krishna, M.P., Mohan, M. (2017). Litter Decomposition in forest ecosystems: a review. *Energy, Ecology and Environment*. 2, 236-249.

Kuruvilla, T., Jijeesh, C. M., Seethalakshmi, K. K. (2014). Litter production, decomposition and nutrient mineralization dynamics of *Ochlandrasetigera*: A rare bamboo species of Nilgiri Biosphere Reserve, India. *Journal of Forestry Research*September 25 (3): 579–584

Lourmas, M., Kjellberg, F., Dessard, H., Joly, H.I. and Chevallier, M. H. (2007). Reduced density due to logging and its consequences on mating system and pollen flow in the African mahogany *Entandrophragmacylindricum*. *Heredity* 99 (2): 151–160.

Matos, E.S., Mendonça, E.S Cardoso, I. M Paulo César de Lima, P. C., and Freese, D. (2011). Decomposition and Nutrient Release of Leguminous Plants in Coffee Agroforestry Systems. *Revista. Brasieira. Ciência do Solo*, 35 (1).

Moro, M. J and Domingo, F (2000). Litter decomposition in four woody species in a Mediterranean climate weight loss N and P dynamics. *Annals of Botany* 86 (6):1065-1071.

Okeke, A. I and Leria, J. I (2005). Decomposition of leaf litter of *Treculiaafricana* Dene var *africana*, J. C Okafor. *Journal of Agricultural Technology and Environment*, 1 (1): 83 – 92.

Okeke A. I., and Omaliko C. P. E. (1992). Leaf litter decomposition and carbon dioxide evolution of some agroforestry fallow species in southern Nigeria. *Forest Ecology and Management* 50: 103–116.

Olson, J. S. (1963). Energy storage and the balance of producers and decomposers in ecological systems. *Ecology* 44: 331.

Pandey, R. R., Sharma, G., Tripathi, S. K. and Singh, A. K. (2007) Litterfall, litter decomposition and nutrient dynamics in a subtropical natural oak forest and managed plantation in Northeastern India," *Forest Ecology and Management* 240 (1–3): 96–104

Rawat, N., Nautiyal, B. P., Nautiyal, M. C (2010). Litter decomposition rate and nutrient release from different litter forms in a Himalayan alpine ecosystem. *Environmentalist*, 30 (3): 279–288.

Saha, S., Rajwar G. S., Kumar, M and Upadhaya, K. (2016). Litter production, decomposition and nutrient release of woody tree species in Dhanaulti region of temperate forest in Garhwal Himalaya *Eurasian Journal of Forest Science,* 4 (1): 17-30

Salahab, Y. M. S and Scholes, M. C (2011). Effect of temperature and litter quality on decomposition rate of *Pinus patula* needle litter. *Sciences* 6: 180–193.

Satchell, J. E. 1974. Litter-interface of animate, inanimate matter. In Dickinson, D. H and Pugh, G. J. F., (eds.) *Biology of Plant Litter Decomposi-tion*, Vols. 1. Academic Press, pp xii – xiv.

Seta, T., Demissew, S., Woldu, Z., Lemenih, M. (2016). Carbon and Nutrient Release Patterns during Leaf litter Decomposition in Boter- Becho Forest, *SouthwesternEthiopia. Journal of Ecosystems and Ecograph* 6: 222.

Steel, R. G. D. and Torrie, J. H. (1980) *Principles and procedures of statistics. A biometrical approach*, 2nd Edition, McGraw-Hill Book Company, New York.

Swift, M. J and Anderson, J. M. (1989). Decomposition. In H, Lieth and M.S.A Weger (eds.) *Tropical Rainforest Ecosystem. Ecosystems of the World* 14B, Elsevier, Amsterdam, 547-560.

Triadiati, S., Tjitrosemito, E., Guhardja, S., Qayim, I and Leuschner, C. (2011). Litterfall Production and Leaf-litter Decomposition at Natural Forest and Cacao Agroforestry in Central Sulawesi, Indonesia. *Asian Journal of Biological Sciences*, 4: 221-234.

Tripathi, O. P., Pandey, H. N and Tripathi, R. S. (2009). Litter production, decomposition and physico-chemical, properties of soil in 3 developed agroforestry systems of Meghalaya, Northeast India. *African Journal of Plant Science*, 3 (8):160-167.

The Plant List(2013). Version 1.1. Published on the Internet; http://www.theplantlist.org/

Yadav, V. and Malanson, G. (2007). Progress in soil organic matter research: litter decomposition, modelling, monitoring and sequestration. Progress in Physical Geography, 31 (2):131–154, 2007.

Yu, S. Y., Jian, F. G., Guang, S. C., Jin, S. X., Li, P. C., Lin, P. (2004). Litterfall, nutrient return, and leaf-litter decomposition in four plantations compared with a natural forest in subtropical China. *Annals of Forest Science* 61 (5): 465–476.

Zhanq D, Hui D, Luo Y, Zhou G. (2008). Rates of litter decomposition in terrestrial ecosystems: Global patterns and controlling factors. *Journal of Plant Ecology* 1:85–93.

Zheng, Z. P., Shanmughave, L. S and Matthew, W. (2006). Litter Decomposition and Nutrient Release in a Tropical Seasonal Rain Forest of Xishuangbanna, Southwest China. *Biotropica* 38 (3): 342–34.