

***DIOSPYROS CRASSIFLORA* (HIERN) SURFACE AND SUBSOIL LEAF LITTER DECOMPOSITION PATTERN ALONG A TIME GRADIENT IN A HUMID RAINFOREST**

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ABSTRACT

Litter decomposition is a crucial bedrock of nutrient recycling, organic matter accumulation, soil physicochemical properties, biodiversity and life support of forest and agroforestry systems. We therefore investigated *Diospyros crassiflora* surface and subsoil leaf litter decomposition pattern along a duration gradient in a humid rainforest. The study was conducted in the nursery of the humid forest research station of the Forestry Research Institute of Nigeria (FRIN) in Umuahia, Abia State. One gram (1g) of *D. crassiflora* fresh leaf litter was placed on the surface and subsoil of 4kg of topsoil contained in 32cm x 20cm polyethene bags; there were a total of 108 bags in a completely randomized experimental design layout and the treatments were the duration gradient of litter decomposition which were: 2, 4, 6, 8, 10, 12, and 14 weeks; on each of the duration, litter was collected from nine of the polyethene bags for laboratory analysis and estimate of decomposition rate. The results showed a significantly high initial decomposition rate ($3.19 \pm 0.13 \text{ \%day}^{-1}$; $4.28 \pm 0.03 \text{ \%day}^{-1}$) in the 2 week duration followed by significant continuous decline until the lowest ($0.04 \pm 0.00 \text{ \%day}^{-1}$; $0.28 \pm 0.02 \text{ \%day}^{-1}$) in the 14 week in the surface and subsoil respectively. There was a positive correlation ($r=0.80$) in decomposition rate between the surface and subsoil leaf litter, which yielded a model with a significant R^2 (0.64), for site-specific estimates of decomposition rate of *D. crassiflora* leaf litter. A steeper and smoother subsoil cumulative percentage decomposition curve showed that leaf litter decomposition was significantly faster in the subsoil than surface soil.

Keywords: moisture, temperature, soil, decomposer, variation

Introduction

Litter decomposition is a biogeochemical process which influences the rate of carbon and nutrient cycling in forest ecosystems (Gonzalez *et al.* 2001). Leaf litter decomposition may also be referred to as mechanical and chemical break down of plant parts from the active or functional stage to a mineral stage which is a point where the original plant material is no longer recognizable (Mugendi & Nair, 1997). Plant litter is an important source of organic

matter to the soil that favours soil biological activity and nutrient cycling (Seta & Zerihun, 2018). Decomposition is one of the major activities in the forest floor (poi de Neiff *et al.* 2006).

The products of complete decomposition are carbon (iv) oxide (CO_2), water and inorganic ions such as ammonium, nitrate, phosphate and sulphate: decomposition is a complex process that is regulated by physical, chemical and biological processes (poi de Neiff *et al.*

2006). The physical processes are leaching and mechanical breakdown; the chemical process is the chemical quality of the litter, while the biological processes are microbial degradation involving several exo-enzymes (Kshattriya *et al.* 1992). Litter decomposition is closely related to biogeochemical cycles. Litter decomposition plays a major role in carbon and nitrogen cycles (Aerts, 2006, Shiels, 2006; Zhanq *et al.* 2008). The carbon balance in terrestrial ecosystems is determined by the difference between input from primary production and the return of carbon to the atmosphere via decomposition of organic matter (Perez-Harguindeguy *et al.* 2000). The rate of litter determines the stores of inorganic elements remaining in the litter component (Ananthkrishnan, 1996). Ecologists have paid considerable attention to litter decomposition in relation to nutrient cycling and soil productivity (Otorokpo, 2012). Nutrient availability is a basic determinant of tree growth and food production. Litter decomposition, therefore, is a pathway in which nutrients are released to the soil and plant nutrients become available for recycling within the ecosystem (Mugendi & Nair, 1997).

According to Taylor *et al.* (1989) the rate of decomposition of the leaf litter is determined by several factors such as: (a) the abundance and diversity of fungi, bacteria and invertebrates present; (b) climatic and seasonal conditions – decomposition is faster in warm, humid climates than in dry or cold climates; and (c) the physical and chemical composition of leaves. Some leaves, such as those of most rainforest plants, are more palatable, while others such as the leaves of eucalypts contain chemicals that soil and leaf litter organisms find difficult to digest; however when decomposers are not present, some break down of organic materials will occur through non-bi-

ological processes. However, it will happen very slowly and nutrients will remain trapped in the unprocessed leaf litter (Mugendi & Nair, 1997).

Litter fall, leaf litter decomposition and nutrient cycling in tree species are continuous processes which are absolutely slow to meet up with the short period of bush fallow system. Litter decomposition is the major avenue of sustaining soil fertility in a tree based ecosystem by providing organic and inorganic elements for nutrient cycling processes and controls nutrient returns to the ecosystem (Wang *et al.*, 2008; Isaac & Varghese, 2020)

The increasing human population has placed greater demand on tropical forests for agricultural crops and other tangible and non-tangible forest products. Nigerian forests and savannah woodlands have been witnessing enormous pressures (Igboanugo 2008). This is mostly due to escalating population pressures in the forms of rising demands for fuelwood and timber, expansion of croplands to meet the rising need to establish developmental projects (Nsien *et al.* 2017; Nsien *et al.* 2020). Okeke and Omaliko (1991) noted that increase in human population in developing countries has contributed to the reduction of fallow periods, declining soil fertility and low productivity of plant products in terms of quality and quantity to sustain the ever-growing population. Tropical forests accumulate huge quantities of nutrients. The efficient cycling of nutrients from the soil to the biomass and back to the soil enables tropical forests to grow on relatively fertile soils of the humid tropics (Otorokpo 2012). Hence, the need to determine the leaf litter decomposition rates of *D. crassiflora* to ascertain its suitability for agroforestry as one of the tropical forest species, which could improve the nutrients status of the soil (nutrient cycling), as well as enhancing food production and ecolog-

ical balance. The study was designed to investigate *Diospyros crassiflora* (Hiern) surface and subsoil leaf litter decomposition pattern along duration gradient in a humid rainforest zone.

Experimentation

Study area

The study was conducted in the Nursery Unit of the Humid Forest Research Station of the Forestry Research Institute of Nigeria (FRIN) in Okwuta-Ibeku, Umuahia, Abia State, Nigeria (Figure 1). The area is a lowland humid rainforest zone and located between longitudes 7°32' and 8°10'E and latitude 5°29' and 6°14'N on an altitude of 122m. The soil type is Ultisol which ranges from sandy loam to sandy clay-loam and has mean annual rainfall of 2238mm, maximum and minimum temperatures: 32°C and 23°C respectively, and relative humidity 65 - 80% (Nsien *et al.* 2017).

Experimental design

In the surface soil litter decomposition experiment, one gram (1g) of *D. crassiflora* fresh leaf litter was placed on the surface of 4kg of topsoil (collected from *D. crassiflora* plantation) contained in 32cm x 20cm polyethene bags. While, in the subsoil litter decomposition experiment, one gram (1g) of fresh leaf litter was placed on the surface of 2kg of topsoil and then covered with 2kg of topsoil in 32cm x 20cm polyethene bags to ensure leaf litter was in the middle of the 4kg of topsoil. The 32cm x 20cm polyethene bags having 4kg of topsoil and 1g leaf litter were 54 in number in each of the two experiments and a total of 108 in a completely randomized experimental design (CRD) layout. The treatments in each of the experiments was the duration gradient of leaf litter decomposition which were 2, 4,

6, 8, 10, 12, and 14 weeks; on each of these durations leaf litter was collected from nine (9) of the polyethene bags for laboratory analysis and estimate of decomposition rate. The polyethene bags were watered daily except on rainy day. Weeding of polyethene bags and the experimental site was done every two weeks.

Data Collection

Leaf litter collected from sampled bags was thoroughly rid of soil, cleaned, and oven-dried at 70°C for 48 hours and weighed in the Laboratory of the Department of Forestry and Environmental Management, College of Natural Resources and Environmental Management, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria. The following parameters were calculated for subsequent data analysis:

Decomposition rate (% day⁻¹) (Okeke & Omaliko, 1992):

$$r = \frac{a - b}{a} \times 100 \times \frac{1}{t} = \frac{(a - b)100}{at}$$

Where

r = relative decay rate (% day⁻¹)

a = initial fresh litter percentage weight (g).

b = leaf litter percentage weight (g) at expiration of duration.

t = duration (days).

Data analysis

Decomposition rate (%day⁻¹) (r) variation between the treatments (duration gradient) was analysed using analysis of variance (ANOVA); Tukey's honestly significant (HSD) test was used to separate the means of decomposition rates; T-test was used to analyse decomposition rate (%day⁻¹) (r) variation between surface and subsoil leaf litter; regression analysis was used to conduct correlation analysis between

surface and subsoil leaf litter decomposition rate and to generate a model for prediction of litter decomposition rate in the two soil layers.

Results

Leaf litter decomposition duration and rate

Duration of decomposition significantly influenced leaf litter decomposition rate in the surface and subsoil in the study area (Table 1). Mean separation showed that decomposition rate was significantly highest in the initial two weeks duration of decomposition both in the surface soil ($3.19 \pm 0.13 \text{ \%day}^{-1}$) and subsoil ($4.28 \pm 0.03 \text{ \%day}^{-1}$); while the significantly lowest leaf litter decomposition rate (soil surface $0.04 \pm 0.00 \text{ \%day}^{-1}$ and subsoil $0.28 \pm 0.02 \text{ \%day}^{-1}$) was in the longest duration of decomposition (14 week) of the study (Table 2). On the soil surface leaf litter decomposition rate significantly slowed down from the $3.19 \pm 0.13 \text{ \%day}^{-1}$ of the 2 week duration to $0.81 \pm 0.59 \text{ \%day}^{-1}$ in the 4 week

duration; and further to $0.67 \pm 0.29 \text{ \%day}^{-1}$ in the 6 week duration; however, decomposition rate significantly and consistently increased again in the 8 week ($1.26 \pm 0.41 \text{ \%day}^{-1}$), 10 week ($1.45 \pm 0.62 \text{ \%day}^{-1}$), and peaked at $1.91 \pm 0.87 \text{ \%day}^{-1}$ in the 12 week duration; after which it drastically slowed to the lowest decomposition rate ($0.04 \pm 0.00 \text{ \%day}^{-1}$) recorded in the study in the 14 week duration (Table 2).

The influence of duration on leaf litter decomposition rate in the subsoil was slightly different from the surface soil; initially, similar to the surface soil there was a significant decrease in litter decomposition rate from the $4.28 \pm 0.03 \text{ \%day}^{-1}$ of the first 2 week to $0.59 \pm 0.06 \text{ \%day}^{-1}$ in the 4 week duration; then there was a significant rise in decomposition rate in the 6 week ($1.29 \pm 0.02 \text{ \%day}^{-1}$), after which there was a continuous (albeit not consistent) decrease in decomposition rate to $0.58 \pm 0.02 \text{ \%day}^{-1}$ (8 week), $0.47 \pm 0.03 \text{ \%day}^{-1}$ (10 week), $0.58 \pm 0.02 \text{ \%day}^{-1}$ (12 week), and $0.28 \pm 0.02 \text{ \%day}^{-1}$ (14 week) (Table 2).

TABLE 1

Analysis of variance (ANOVA) of surface soil and subsoil leaf litter decomposition duration and rate.

Sources	SS	df	MS	F	P value
Surface soil LLDR	18.432	6	3.072	249.033	2.1E-13
Subsoil LLDR	35.986	6	5.998	782.462	7.35E-17

* $p \leq 0.05$ = significant effect of duration of leaf litter decomposition; LLDR = leaf litter decomposition rate.

TABLE 2

Mean separation of duration and rate of leaf litter decomposition variation between surface soil and the subsoil.

Duration	2WK	4WK	6WK	8WK	10WK	12WK	14WK
Surface	3.19 ± 0.13^a	0.81 ± 0.59^b	0.67 ± 0.29^b	1.26 ± 0.41^c	1.45 ± 0.62^c	1.91 ± 0.87^b	0.04 ± 0.00^d
Subsoil	4.28 ± 0.03^e	0.59 ± 0.06^f	1.29 ± 0.02^g	0.58 ± 0.02^h	0.47 ± 0.03^f	0.58 ± 0.02^h	0.28 ± 0.02^i

*Means with same letter are not significantly different.

Surface soil and subsoil leaf litter decomposition rate pattern

The pattern of leaf litter decomposition rate in the surface soil and the subsoil are significantly correlated ($r = 0.80$) and yielded a model ($R^2 = 0.64$) that significantly (Table 3) connects the two and can be used to estimate one from the other i.e. surface soil decomposition rate can be calculated from the subsoil decomposition rate and vice versa using the model equation below:

$$\text{Subsoil LLDR} = -0.32 + \text{surface soil LLDR} (1.101)$$

Where:

Subsoil LLDR = subsoil leaf litter decomposition rate;

Surface soil LLDR = surface soil leaf litter decomposition rate.

The decomposition curve (Figure 1) of leaf litter in the surface and subsoil sloped from left to right (indicative of a negative slope) i.e. a decreasing decomposition rate versus increasing decomposition duration. The subsoil cumulative percentage decomposition rate curve was steeper and smoother than the surface soil curve (Figure 2). This showed that the subsoil significantly influenced *Diospyros crassiflora* leaf litter decomposition than the surface soil. This is corroborated by the fact that more than 50% of the leaf litter was already decomposed in the subsoil by the two week duration relative to 34.19% in the surface soil within the same time duration (Figure 2).

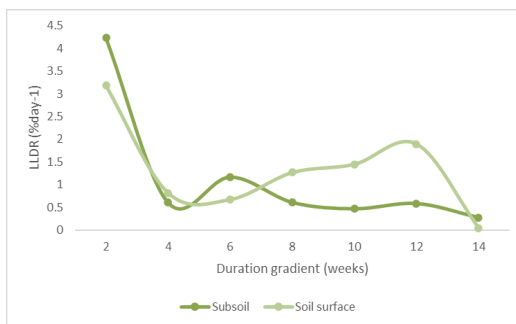


Fig. 1. Leaf litter decomposition rate (LLDR) variation between surface soil and subsoil.

TABLE 3

Regression analysis of relationship between surface soil and subsoil leaf litter decomposition rate.

Sources	df	SS	MS	F	p-value
Regression	1	7.414	7.414	8.769	0.032
Residual	5	4.227	0.846		
Total	6	11.641			

*p value ≤ 0.05 = significant relationship.

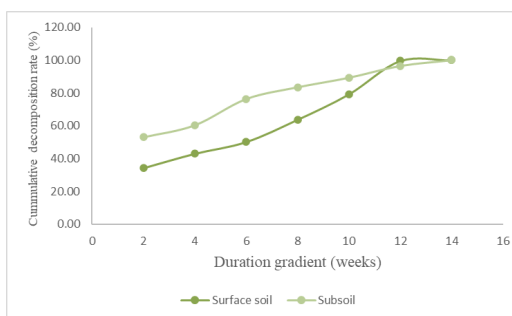


Fig. 2. Cumulative leaf litter decomposition rate (%) variation between surface soil and subsoil.

Discussion

Leaf litter decomposition rate is associated with the rate of nutrient recycling in forest ecosystems. High leaf litter decomposition rates in any species therefore inadvertently recommends it for use in agroforestry systems. There was a significantly high initial decomposition rate in the first two week duration of leaf litter in the surface soil (34.19%) and subsoil (53.10%) found in this study. This is contrary to the findings of Otorokpo (2012) who reported an initial decomposition rate of 28% in *Entandrophragma cylindricum* and Hartemink and Sullivan (2001) who reported 30% in *Piper aduncum* and *Gliricidia sepium*. According to Okeke and Omaliko (1992) high initial decomposition percentage is sometimes associated with high initial content of water soluble materials, simple substrates, the breakdown of the leaf litter by decomposers (especially micro-flora) and the removal of leaf litter particles by animals such as termites. Furthermore, the sequence of litter decomposition normally involves the initial breakdown of plant material into large chunks, followed by the leaching away of soluble materials, and finally decomposer organisms go to work to breakdown the litter into micro particles (Perez-Harguindeguy *et al.* 2000; Hattenschwiler & Jorgensen, 2010; Giebelmann *et al.* 2013). The rate at which these sequence proceeds is determined by the quality of litter, the physicochemical environment, and the decomposer organisms (Giweta, 2020) which are equally affected the environment. Therefore, due to the tremendous diversity of litter quality between plant species and variability of soil physicochemical properties (e.g. pH, moisture) and climatic factors (e.g. temperature, rainfall) decomposition rate will always vary between different species and environment.

Also, *D. crassiflora* leaf litter decomposition was complete by the 14 week duration in this study. This is contrary to Gartner and Cardon (2004) who reported 100% decomposition rate in the 12 week duration for three bush fallow species in Umuahia, Nigeria. The results is also at variance with Ekpendu (2003) who obtained 100% leaf litter decomposition in *Irvingia wombulu* within 30 week duration; Otorokpo (2012) in *Entandrophragma cylindricum* within 22 week duration; Ojevwe (2007) in three ornamental/ landscape woody plant species in Umuahia, Nigeria in 28 week duration. This again underscores the effect of leaf litter quality diversity and variations in climatic and edaphic factors between these species. For example, literature (Meentemeyer 1978; Gholz *et al.* 2000; Kumar *et al.* 2010; Hasanuzzaman & Hossain, 2014) is replete with evidence of low temperatures effects on the retardation of soil microbial activity. Therefore, we propose that climatic and soil physicochemical data should always be reported alongside decomposition rates in litter decomposition studies. Climatic factors such as temperature and precipitation, as well as soil chemical properties like pH and moisture, soil physical properties like structure and texture provide a background idea of factors responsible for the pattern of observed litter decay rate. These will also enable a more robust basis for comparison of results and the subsequent usefulness and application of the findings.

Subsoil litter decomposition was significantly faster than the surface soil in this study. This is contrary to (Gill & Burke 2002) who reported that *Bouteloua gracilis* root decomposition was 50% slower at 1m depth than at 10 cm depth. Although, root decay is slower than leaves litter (Giweta, 2020) we glean from the findings of (Gill & Burke, 2002)

the effect of soil depth on litter decomposition rate. Most studies on litter decomposition in the tropics are based on surface soil, hence the need for more studies on the effect of soil depth on leaf litter decomposition. However, it is obvious in this study that moisture and decomposers as factors of litter decay (Pant & Tiwari 1992; Devis & Yadav 2007; Tripathi *et al.* 2009) were obviously more present in the subsoil than the surface soil. This is because when water has evaporated from the surface soil the subsoil still retain some moisture and therefore more suitable for decomposer activity than the surface soil. This therefore explains the significantly faster decomposition rate in the subsoil.

Conclusion

D. crassiflora leaf litter decomposition rate was significantly influenced by the duration of leaf litter in the soil i.e. leaf litter decomposition was constant for as long as the litter makes contact with soil; this was responsible for the significant high correlation in decomposition rates in both surface soil and subsoil and the significance of the regression model for decomposition rate estimation. Leaf litter decomposition in the surface soil and subsoil showed similar pattern initially but varied afterwards i.e. there was significantly high decomposition rates in the initial two week duration in both surface soil and subsoil; subsequently however, decomposition rate slowed down in the surface soil than the subsoil leading to a more consistent decomposition rate in the subsoil than in the surface soil i.e. this is evidenced by the sharper and steeper curve of subsoil decomposition rate than the surface soil. The subsoil therefore significantly influenced leaf litter decomposition than the surface soil.

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