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LITTER DECOMPOSITION AND NUTRIENT RELEASE DYNAMICS IN *Allanblackia floribunda* (Oliv) AGROFORESTRY SYSTEM UNDER A HUMID TROPICAL ENVIRONMENT OF SOUTH EAST NIGERIA

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Abstract

Field experiments were conducted between 2017 and 2018 at Forestry Research Institute of Nigeria, Humid Forest Research Station, Umuahia, South east Nigeria, to study litter decomposition and nutrient release dynamics in Allanblackia floribunda (Oliv) agroforestry system. The experiments were all laid out in a randomized complete block design with three replications. The litter bag method was employed for the decomposition study. The C:N ratio was 10.6:1. The cumulative mean leaf litter decomposition at 48 weeks after litter placement (WALP) was 91.0%, with a biphasic mode of decay, having an initial rapid phase of mass loss (4 – 24 WALP) and a later slower phase (28 – 48WALP). Leaf litter half-life was obtained at 8 WALP while the turn over coefficient k (decay constant) was 4.62/year. The percentage cumulative mean nutrient release for N, P, K, Ca and Mg increased up to 24 or 28 WALP and thereafter stabilized up to 40 WALP, after which a slight decline in P, K, Ca and Mg and a significant drop in nitrogen occurred. However, Organic carbon increased significantly up to 32 WALP, beyond which no significant changes occurred in the cumulative release from the leaf litter. The high rate of litter decomposition and subsequent release of nutrient make A. floribunda leaf litter a good source of organic manure for soil fertility restoration and improved growth and yield of arable crops in the humid tropical environment of south east Nigeria.

Key Words: *Litter decomposition, Nutrient release, Allanblackia floribunda, Agroforestry systems*

Introduction

Litter decomposition has been recognized as an essential part of the forest ecosystem. It is a sequential process that results in the breakdown of complex organic compounds by decomposers into simpler substances, releasing nutrients as by-product (Saha, 2016). The decomposition of forest litter is the principal pathway for producing organic and inorganic materials in the process of nutrient cycling and management of soil nutrient reserve (Rawat *et al.,* 2010). Decomposition of leaf litter is a major source of nutrients in forest ecosystems. Ecologists have given ample consideration to litter decomposition as regard to nutrients cycling and soil fertility. The distinct proof is that litter decay has a marked effect on the availability of nutrients. The availability of nutrients is a basic determinant of tree growth and food production. Litter decomposition is an important avenue in which plant nutrients are returned into the soil and become available for recycling within the ecosystem (Chandraa *et al.,* 2015).

Leaf litter decomposition pattern is in three stages: (1) Leaching, this is the initial stage, where leaching and nutrient release dominate (2) Net accumulation or immobilization, this is the stage where nutrients_increase due to the presence of microbes (3) Net release, this is the stage where the nutrient mass decreases (Seta *et al.,* 2016). However, these stages do not always appear sequentially in practical experiments. For example, the immobilization phase might be absent, especially in litter with high N concentrations (Seta *et al*., 2016). The products of complete decomposition are carbon dioxide, water and inorganic ions such as ammonium, nitrate, phosphate and sulphate (Triadiati *et al.,* 2011).

The rate of litter decay and nutrient release is regulated by many factors such as prevailing climatic variables, litter chemistry and activity levels of decomposers' community (Ranucci *et al.,* 2022; Kuruvilla *et al*., 2014). Climate and litter quality are the two most important factors in determining the litter decomposition rate (Bisht *et al.,* 2014: Rawat *et al.,* 2010).

Litter decomposition varies under different climatic conditions. Climate influences the nature and rapidity of decomposition of plant remains on soil surface and thus, determines the nature and abundance of the organic matter (Swarnalatha and Reddy, 2011). Krishna and Mohan. (2017) reported that moisture and temperature are among the most crucial variables because they affect both the development of plant cover and the activities of microorganism which are highly critical factors in soil formation. Similarly, Tan *et al.* (2021) reported that high relative humidity and temperatures triggered the activities of decomposers. Where substrate is available, soil microbial activity increases exponentially with soil temperature, with microbial activity often doubling with a 10°C increase in temperature (Bernice *et al.,* 2022). As a result, the higher the temperature and precipitation the higher the rate of fresh litter decomposition (Bisht *et al.*, 2013). Generally, decomposition increases with temperature in an exponential manner. Thus, for every 10 degrees rise in temperature, decomposition increases by a factor of two (He and Yu, 2016).

Litter quality could be referred to as the inherent chemical and structural features that guide the activity of decomposer organisms, which partially regulate the rate of decomposition (Salah and Scholes, 2011). Some tree leaves contain proportionately large amounts of tough structural compounds that make them difficult for microorganisms to break into smaller fractions and barely eaten by macro invertebrates. For example, pine needles may not support as many bacteria and fungi as the more nutritious teak leaves (Krishna and Mohan, 2017).

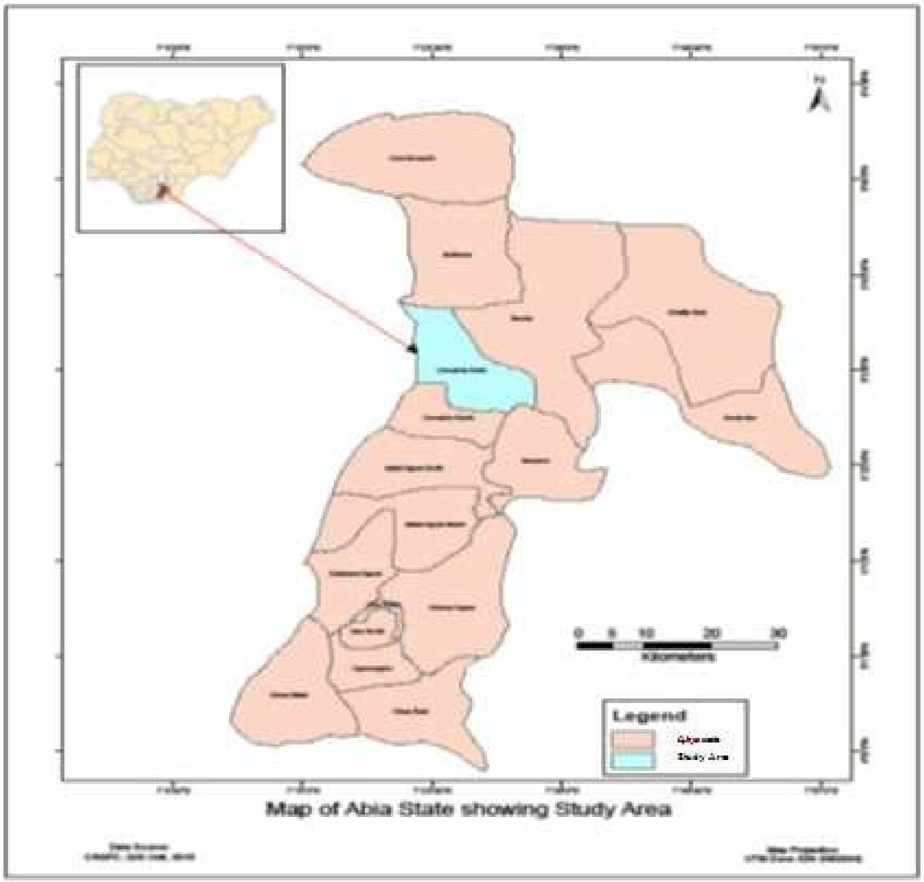
Substrate quality has been related to the nitrogen concentration (N), the lignin content and the C:N ratio (Seta *et al*., 2016; Abugre *et al.,* 2011). High initial concentrations of nitrogen (N) or phosphorus (P) in litter increases decomposition rates. Unlike nitrogen and phosphorus, a high initial 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).

Allanblackia floribunda is a dioecious multipurpose tree which belongs to the family *Clusiaceae or Guttiferae.* It is an evergreen tree that grows mainly in tropical rainforests but is also found in cultivated farmland areas (Buss and Tissari, 2010; Koyejo *et al*., 2020a). The seed of *A. floribunda* is rich in edible oil and has some healthy physicochemical characteristics that gives it an edge over other oils (Folarin *et al* 2017; Crockett, 2015). The seed oil is being developed as a rural-based enterprise for its application in the manufacture of margarine (Buss and Tissari, 2010). This has made the demand for the seeds to far exceed the supply from the natural forest and remnants on farms and the risk is that wild seed collection of *Allanblackia* spp may lead to over-exploitation of this resource in such a manner that will impair natural regeneration as well as biodiversity conservation (Oppong, 2008; Kattah, 2010).

To address the challenges associated with over-exploitation and decreasing *A. floribunda* abundance in the forests, there is need to introduce the species into the existing farming systems through agroforestry in homestead farms and on-farm conservation. *A. floribunda*-based agroforestry system will not only serve as an alternative source of income to farmers, but also contribute to the maintenance of soil nutrient pool through litter decomposition and its subsequent release of nutrients. 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). Hence, the objectives of the study were to determine the decomposition and nutrient release pattern of *A. floribunda* leaf litter.

Study Area

The study was carried out in the *Allanblackia floribunda* plantation of Forestry Research Institute of Nigeria (FRIN), Humid Forest Research Station, Umuahia, Abia State south-eastern Nigeria. Umuahia lies between latitude 5°34' N and longitude 7°34' E (Ujoh *et al*., 2011). It has two major seasons, dry season and rainy season. It has an annual mean rainfall of 2, 278mm, with eight months of precipitation, which starts from early March to late October the rainfall is bimodal. The dry season is characterized with a period of short spell of dry/cool season referred to as harmattan (Ochege and Okpala-Okaka, 2017; Ujoh *et al*., 2011). The mean annual maximum temperature is 31°C with little daily variations. Mean daily insolation is 4.8 h (Ochege and Okpala-Okaka, 2017), while the mean relative humidity varies from 60 to 90% (Kalu *et al*., 2012). Geologically, Umuahia is within the Benin formation which comprises of shale and sediments with intercalation of thin clay beds. It is a part of the coastal plain sands of the Cenozoic Niger Delta region of Nigeria (Nnaji *et al.,* 2019).



Map of Abia State showing the study area
Source: Nsien *et al.* (2020).

Methods

The study was conducted from August, 2017 to July, 2018.A randomized complete block design (RCBD) with three replications was used in the study. The litter bag technique (Devendar *et al.,* 2022) was utilized in the leaf litter decomposition experiment under field condition. One hundred and fifty plastic mesh litter bags measuring 15cm x 20cm x2cm were used.

Materials

Fresh leaf litters were collected, washed with water to remove sand and air-dried. 10g leaf litter of the species was placed in each of the plastic mesh litter bags. Litter bags were buried at a depth of 15 cm in the *Allanblackia floribunda*-based agroforestry system. Fifty litterbags were placed at different locations in each block and the locations were marked with pegs for easy identification.

Sampling of leaf litter weight loss was done at the following periods: 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48 weeks after litter placement (WALP). At each sampling interval, 3 litter bags were randomly harvested from each block. The litter bags were washed with water to remove soil particles, fine roots and living organisms adhering on leaf litter. The harvested leaf litter was sun – dried and later oven – dried in small paper bags at

70°C for 48hrs. The dry weight of the leaf litter was analysed for N, P, K, Ca, Mg, organic carbon and organic matter.

Total nitrogen was determined in a kjeldahl apparatus (Hicks *et al*., 2022); available phosphorus was extracted in Bray and Kurtz, No. 1 (Flavio *et al.,* 2011) and its concentration measured by the Vanado-molybdate blue colour method (Nalumansi *et al*., 2020); exchangeable bases (Ca, Mg, K and Na) were extracted with one normal neutral ammonium acetate solution (IN NH4OAc at pH 7.0) as described by Maniyunda *et al.* (2019). Exchangeable K and Na concentrations in the extract were read on an EE2 flame photometer (Asch *et al*., 2022) while Ca and Mg concentrations were read in Atomic Absorption Spectrophotometer (AAS) (Bisergaeva and Sirieva, 2020). Organic carbon was determined by wet dichromate oxidation method (Sato *et al.,* 2014). Organic matter content was obtained by multiplying organic carbon values by 1.724 (Shamrikova *et al*., 2022).

The data collected for the leaf litter decomposition were used for the following computations.

Cumulative leaf litter decomposition (%) per sampling interval

At each sampling period, the computation method described by Koyejo *et al*., (2020b) was used to determine the cumulative leaf litter decomposition rate (%) as follows.

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

where:
D = Cumulative leaf litter decomposition weight loss (%)
a = Initial weight at the beginning of the experiment.
b = Present weight at the sampling interval.

Leaf Litter Half – life and Full-life Estimations

A quadratic equation $Y= a + b - cx^2$ was employed to calculate the estimated Leaf Litter half – life and full life (time of 50% and 100% leaf litter decomposition) of *A. florib*unda. The various sampling intervals (X) and the cumulative leaf litter decomposition percentages overtime (Y) were used for the computation. The mean cumulative percentage losses in dry weight over time were used along with the predicted values obtained from regression equation to calculate the leaf litter half-lives and full-lives (total decomposition rates).

Turnover Coefficient

Olson's equation was used to compute the turnover coefficients of leaf litter decomposition rates of *A floribunda* as follows (Ranucci *et al*., 2022):

$$K_1 = 0.693/\ t_{50}$$

Where:
K_1= litter turnover coefficient
t_{50}= litter half-life overtime (either weeks, months or years).

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

Relative leaf litter disappearance/decay rate (% day^{-1} sampling interval^{1}) was computed according to the procedures of Koyejo *et al*., (2020b) as follows:

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

where:
r = relative leaf litter decomposition/decay rate (% day^{-1} sampling interval^{1}),
a = cumulative leaf litter decomposition percentage at the previous sampling interval,
b = cumulative leaf litter decomposition percentage at the present sampling interval,

t = time (number of days) between the present and the previous sampling intervals.

Nutrient release of the decomposing leaf litter

Nutrient release of the decomposing leaf litter of *A. floribunda* was derived as:

$$\% \text{ nutrient release} = \frac{M_o C_o - M_t C_t}{M_o C_o} \times 100$$

Where:

C_t = the concentration of element in the leaf litter at the time of sampling,

C_o = the concentration of elements in the initial leaf litter kept for decomposition,

M_t = the oven dry mass of leaf litter in the bag at the time of sampling,

M_o = the initial dry mass of leaf litter sample kept for decomposition (Cissé *et al*., 2021: Yang *et al.*, 2021).

Positive values of release indicate net loss of the nutrient from decomposing litter, whereas negative values indicate immobilization of the nutrient.

Physical and Chemical Analysis of Leaf Litter Samples

Leaf litter nutrient concentrations

Ten grams (10g) of thoroughly mixed and oven dried samples of *A. floribunda* leaf litter was milled and sieved in 1mm sieve. From the oven-dried milled sample, 0.2g was used to determine, N, P, K, Ca, Mg and Organic C.

Data Analysis

The data obtained from the litter decomposition and nutrient release studies were subjected to analysis of variance (ANOVA) and Fisher's least significant difference (F-LSD) at $P < 0.05$ using Genstat 3 discovery edition (Genstat, 2007). Simple regression analysis was used to determine the relationships between the rate of decomposition and time. Correlation between rate of decomposition and nutrient release was determined using Pearson's correlation.

Results and Discussion

Soil analysis

The soil properties summarized in Table 1 indicate that soil texture at the agroforestry site was sandy loam. Soil Organic matter (OM) and Nitrogen (N) in 2017 were generally high (3.16 and 0.30%respectively) and above the critical values of 20% OM and 0.15% N reported by Fairhust (2012) as compared to the lower values (1.3% OM and 0.07% N) obtained in the younger *Allanblackia* plantation of 2016. The soil of 2017 was also higher in soil pH, Calcium, Potassium, Sodium, Effective cation exchange capacity (ECEC) and base saturation but lower in Phosphorus and Magnesium compared to 2016. Iwuagwu *et al.* (2017) made similar observation.

Table 1: Some physical and chemical properties of the agroforestry site at Forestry Research Institute 0f Nigeria, Umuahia, in 2016 and 2017

Soil Properties	2016	2017
Physical Properties		
Sand	71.04	73.6
Silt	12.73	9.7
Clay	16.23	16.7
Texture	Sandy Loam	Sandy Loam
Chemical properties		
pH (H_20)	4.77	5.77
Phosphorus (Mg/kg)	35.97	20.85
Nitrogen (%)	0.07	0.3
Organic Carbon (%)	0.75	1.83
Organic Matter (%)	1.30	3.16
Calcium (Cmol kg^{-1})	1.73	6.40
Magnesium (Cmol kg^{-1})	0.80	0.60
Potassium (Cmol kg^{-1})	0.07	0.10
Sodium (Cmol kg^{-1})	0.19	0.36
Exchangeable Acidity (Cmol kg^{-1})	1.25	0.4
ECEC (Cmol kg^{-1})	4.08	7.86
Base Saturation	68.71	94.79

Cumulative leaf litter decomposition (%) per sampling interval of A. floribunda

The cumulative leaf litter decomposition rates (%) over time of *A. floribunda* are shown in Table 2. At 4weeks after litter placement (WALP), leaf litter decomposition rate (39.33%) had significantly ($p< 0.05$) the lowest value. There was no significant difference between the decomposition rate of 28, 32 36, 40, 44and 48 WALP. In all, there was 91% decomposition at the end of the study period at 48 WALP indicating an exponential pattern of leaf litter decomposition. Litter decomposition can either have an exponential pattern or a linear pattern. This depends on some factors such as the tree species, the climatic condition of the site, the soil type and the method of application of leaf litter for decomposition (Dhanya *et al*., 2013). The cumulative mean leaf litter decomposition of 39.3% at 4 WALP is similar to that of Frasson *et al.*, (2016) who observed 40% decomposition of leaf litter of *Schinus terebinthifolius* at 4 WALP. The high cumulative mean leaf litter decomposition of 91.0% at the end of the study at 48 WALP is in line with the reports of Abugre *et al.,* (2011) for *Jatropha curcas* (97.0%) and Okeke and Leria (2005) for *Treculia africana* (96.7%). On the other hand, Chandraa *et al*., (2015) reported cumulative mean decomposition of pine and oak to be 52.4% and 63.8% after 2 years of litter placement. This slow rate of decomposition could be as a result of the litter quality.

Litter quality is one of the factors that determine rates of decomposition and release of nutrients from organic residues (Zhou *et al.,* 2014; Mahari, 2014). Initial nitrogen (N), lignin (LG), and polyphenol (PP) concentrations, and ratios such as C: N, LG: N, and PP: N in the leaf litter are some of the useful indicators that have been shown to influence decomposition rates (Abbasi *et al.,* 2015). The fast decomposition rate observed in this study was probably due to the relative low C: N of 10.6. C: N ratios have been well correlated with faster decomposition (Seta *et al.,* 2016; Bargali *et al.* 2015; Geurts *et al.,* 2010). The optimal C/N ratio that is generally accepted is 10:1 (Radosevich and Rhine, 2006). A ratio of 15:1 or more may not have enough nitrogen available. This makes the microbes to pull in inorganic nitrogen from the soil, slowing down mineralization. Any ratio over 30:1 is considered extremely high and can result in some soil nitrogen deficiencies. This is because the microbes tend to be more competitive than the plant and will completely exhaust the nitrogen resources in the soil (Mesic *et al.,* 2010).

Table 2: Cumulative leaf litter decomposition (%) of *A. floribunda* per sampling interval

Time (weeks)	Leaf litter decomposition (%)
4	39.33
8	52.73
12	56.30
16	65.57
20	75.63
24	81.40
28	84.17
32	86.37
36	88.77
40	90.80
44	90.50
48	91.00
Mean	75.21
LSD ($p< 0.05$)	8.66

Generally, litter decomposition increased significantly overtime. There was an initial phase of rapid increase in the rate of decomposition between the 4 and 24WALP (i.e., the first 6 months), followed by a later slower phase from 28 to 48 WALP. At the end of 48 WALP, 9% of the initial leaf litter for decomposition was remaining. This suggest that *A. floribunda* leaf litter followed a biphasic mode of decay, having an initial rapid phase of mass loss (4− 24 WALP), followed by a later slower phase (28−48 WALP). This is in line with the study of Dhanya *et al.* (2013) who noted a biphasic mode of decay in leaf litter of *Ficus benghalensis* having an initial rapid phase of mass loss in first 24− 28 WALP followed by a later slower phase from 32 to 48 WALP and Triadiati *et al.* (2011) who observed rapid decay in the first 8 WALP in a natural forest and cacao agroforestry. Decomposition process has been reported to have two phases, a leaching phase which is rapid and a post-leaching phase which is slower. These phases are governed by different litter quality parameters (Swarnalatha and Reddy, 2011). With the high litter decomposition obtained in the present investigation, leaf litter of *A. floribunda* could be utilized in the traditional farming system to improve soil organic matter content and soil fertility in farmlands and agroforestry systems in south eastern Nigeria.

Relative Leaf Litter Disappearance/Decay Rates (% day^{-1} sampling interval^{-1})

The relative leaf litter disappearance/decay rates are shown in Table 3. The 4 (1.41%) and 40 or 48 (0.01 - 0.02%) WALP gave significantly the highest and lowest relative leaf litter disappearance or decay rates respectively. The initial high relative disappearance/decay rate (1.41) observed within the first 4 WALP is in accordance with the reports of Hasanuzzaman and Hossain (2014); Triadiati *et al.* (2011); Matos *et al.* (2011) and Abugre *et al.* (2011). The initial rapid phase of decomposition could be attributed to breakdown of small soluble carbon molecules, like starches, sugars and amino acids, leaving behind the more recalcitrant molecules like lignin, cellulose, fat and waxes. These soluble carbon molecules are rich in energy and are easily broken down by decomposers (Hasanuzzaman and Hossain, 2014; Abugre *et al*., 2011; Matos *et al.,* 2011). In contrast the later stage of decomposition is dominated with the degradation of larger macromolecules, such as cellulose, hemicelluloses, and lignin which is usually a slow process (Zheng *et al.,* 2018; Matos *et al*., 2011).

There was no significant difference between the 12, 28, 32, 36, 40, 44 and 48 WALP in litter decay rates but a significant decrease in decomposition from 4 to 12 WALP. At 16, 20 and 24 WALP there was a slight increase and relative disappearance rate slowed down from the 28 through 48 WALP.

***Turnover Coefficient (K_1), Leaf Litter Half – life and Full-life of A. floribunnda*.**

The turnover coefficient (k_1), leaf litter half – life and full-life of *A. floribunda* are presented in Table 4. The turnover coefficient (k_1) per week and per year were 0.09 and 4.62 respectively. The decay rate coefficient (k) which was 4.62 yr^{-1} (0.01 day^{-1}) is similar to that reported by Hossain *et al.* (2011) for three tropical agroforestry tree species (*Melia azadirachta, Azadirachta indica,* and *Dalbergia sissoo*) which ranged between 3.91- 6.67 yr^{-1}.

Table 3: Relative leaf litter disappearance/decay rates of *A. floribunda* (% day^{-1} sampling $interval^{-1}$)

Time (weeks)	Leaf litter decomposition (%)
4	1.41
8	0.48
12	0.13
16	0.33
20	0.36
24	0.32
28	0.10
32	0.08
36	0.09
40	0.01
44	0.03
48	0.02
Mean	0.28
LSD ($p < 0.05$)	0.29

Table 4: Turnover Coefficient (K_1), Leaf Litter Half – life and Full-life of *A. floribunda*

Leaf litter	Day	Week	Year
Half- life $t_{(½)}$	55.72	7.96	0.15
Full-lifet $_{(1.0)}$	409.08	58.44	1.12
Turnover coefficient (K_1)	0.01	0.09	4.62

Hasanuzzaman and Hossain (2014) also reported a decay constant which ranged between 0.88– 2.34 yr^{-1} for *Mangifera indica, Zizyphus jujuba, Litchi chinensis, and Artocarpus heterophyllus*. Triadiati *et al* (2011) reported that for tropical trees when decay constant is greater than 1.0, this means that leaf litter turnover occurred in a year or less than a year. Decay constant varies from region to region. In the temperate forests decay constant has been evaluated to be 0.9. In the tropics decay constant is evaluated due to regionality and in many African forest's turnover coefficient (decay constant) is usually high (k>2), while forests found in Southeast Asia and the Neotropics have medium to high decay constant (k = 1-2) (Swarnalatha and Reddy, 2011). Very high decay constant of approximately 4 (k ˜4) are observed mainly in African tropical forests and agroforest, indicating rapid nutrient cycling (Triadiati *et al.,* 2011). However, low decay constant of less than 1 (k<1) had been reported in the tropics and this could be attributed to litter type, season and altitude (Swarnalatha and Reddy, 2011). Triadiati *et al.* (2011) reported that decomposers are the major causes for variation in decay constant, stating that microbes are fundamental in nutrient cycling in ecosystems. The main source of energy for microbial life in soil is organic matter. The quantity and the quality of the organic matter in a certain ecosystem determine the population and activity of the soil microbes. Therefore, the quality of litter affects microbial activities and nutrient retention in a system.

The table further shows that half-life (50% decomposition) of the leaf litter could be obtained in 8 weeks while 100% leaf litter decomposition could be obtained in one year. The half- life of 8 weeks observed in this study is similar to that reported for *Cordia macrostachyus* (Mahari, 2014) but contrary, to that reported by Dhanya *et al.* (2013) for *F. benghalensis* (5.54 months) and Kuruvilla *et al.* (2014) for *M. ritcheyi* (2.57 months). These differences could be as a result of several factors such as litter quality, climatic and soil conditions (Dhanya *et al.*, 2013).

Regression equation parameters, observed and expected mass losses (% decomposition) of A. floribunda leaf litter

The regression equation function, Y= a + b - cx^2, showed a good fit for leaf litter decomposition of *A. floribunda* (Table 5). The percentages of leaf litter decomposition observed and calculated at the end of the study (48 WALP) are also shown in Table 5. The relative decay rates for the observed and expected at 48WALP were 0.27 and 0.26 respectively, which were similar, indicating that the leaf litter decomposition of *A. floribunda* can be used to predict decomposition rate over time.

Nutrient release of A. floribunda leaf litter

The initial nutrient content of the leaf litter is shown in Table 6, while Table 7 shows the cumulative release of nutrient at time *t*, from the leaf litter of *A. floribunda* kept for decomposition. The initial values for N, P, K, Ca, Mg and organic carbon were 1.51%, 0.38%, 0.58%, 2.16%, 0.72% and 16.00% respectively with a C; N ratio of *A. floribunda* was 10.6:1. The release of C, N, P, +K, Ca, Mg and org. C increased with time to peak values before decline occurred (Table 7). There was an initial rapid release and by the 8 WALP, more than 50% of all nutrient elements (except P). The rapid release phase was followed by a slower phase and finally by a reduction in the release of all nutrient elements at the 44 and 48 WALP. The rapid release of nutrients observed at the early stage (8 WALP) may be due to the loss of the soluble forms of nutrients at the initial stages of decomposition which was also noted in the study of Asigbaase *et al.* (2021); Gaisie *et al.* (2016). Conversely, the slower release of nutrients at the later stages of leaf litter decomposition may be due to microbial oxidation of refractory components, physical and biological fragmentation. This is similar to the reports of Cissé *et al.* (2021); Gaisie *et al.* (2016) and Hasanuzzaman and Hossain (2014).

The decrease in cumulative nutrient release observed at 16 WALP was as a result of immobilization of nutrients which could be caused by nutrient accumulation in the decomposing leaf litter from fallen litter, precipitation, throughfall, stemflow and the growth of fungal hyphae (Kuruvilla *et al.,* 2014). The total cumulative release of nutrients from *A. floribunda* leaf litter (89.20% N, 94.70% P, 93.70% K, 89.69% Ca, 89.00% Mg and 91.31% Org. C) was higher than that recorded for Alder leaf litter which released 76% nitrogen, 81% phosphorus and 59% potassium in a period of 1 year (Tripathi *et al*., 2009). The different nutrients in decomposing leaf litter have different pattern of release overtime. These nutrients are held with different strength in litter structures (Okoh and Edu, 2019).

There was significant increase in the release of N from the 4-16 WALP, while from 24-40 WALP there was no significant increase. A significant ($p < 0.05$) reduction in cumulative release of nitrogen was recorded at 44 and 48 WALP. The rapid release of N in this study was probably due to the low C:N ratio of 10.6 and leachable components of the leaf litter. With a low C: N ratio of 10.6 :1, humification was faster as the leaf litter made little demand on soil nitrogen for it to be converted to humus. This result is similar to that of Seta *et al*., (2016) in Boter-Becho forest in Ethiopia characterized by a mixture of tree species and Rodríguez *et al.* (2015) in *Coffea arabica*. C:N ratio is important in the release of nitrogen but a high C:N ratio will result in immobilization. Leaching can also cause about 25% release of N from decomposing leaf litter especially at the early stage (Seta *et al.,* 2016).

P release was slow at the beginning of the study, at 4 WALP only 12% of the initial P in the leaf litter was released and thereafter, there was a significant release of P at16 and 24 WALP. The observed initial slow release of phosphorus in the first 12 WALP which might be due to the retention of the element in the microbial tissues (Dhanya *et al.,*2013). The later rapid release at 16 WALP was because of susceptibility to leaching and microbial decomposition (Tiwari and Joshi 2013; Han *et al.,* 2011). Leaching of phosphorus results in rapid loss of water-soluble compounds, as phosphorus is usually a constituent of metabolites enzymes system of the plant sap (Cheesman *et al*., 2010).

There was no significant difference in the release of P from 28 to 48 WALP, while the cumulative release of P at the end of the study was 94.7%. Potassium (K) release increased up to 16 and 24 WALP, after which no significant increases occurred. The rapid release of K in the first 8 WALP from the decomposing leaf litter in the present study was mainly because K is a non-structural element in plant, highly mobile and most leachable cation during decomposition. In plant tissues, K is not strongly bonded to complex organic molecules hence microbial activities are not required for its release from detritus. This was supported by other similar works such as Seta *et al.* (2016); Matos *et al.* (2011); Chhetri *et al.* (2012) and Hasanuzzaman and Hossain

(2014). The cumulative release of K at 48 WALP was 93.7%.

The release of Calcium (Ca) and Magnesium (Mg) from the leaf litter mostly followed similar pattern. The cumulative release of Ca increased initially up to 16 WALP, after which it became constant from 20 up to 48 WALP. There was also an initial increase in the release of Mg with 53.10% released at 4 WALP. The initial rapid release of Ca with the loss of dry matter was due mainly to mobility and leaching. Mg also had a rapid release with loss of dry matter (8 WALP) because it is generally, a mobile nutrient in leaf litter and vulnerable to leaching since it is a constituent of the structural make-up of the plant, such as the cell wall (Yue *et al*., 2021; Jaeyeob *et al.,* 2015). Although Ca has been found to have lower mobility than K and Mg, it is more mobile than the macronutrients N and P (Qiu *et al.,* 2012). There was no significant difference in the release of Mg from 4 to 12 WALP and from 16 to 24 or 48 WALP. The total release of Ca and Mg at the end of the study period was 89.67% and 89.0% respectively.

Organic carbon release increased significantly up to 32 WALP and thereafter. There was no significant difference in the cumulative release of organic C up to the 32-48 WALP. The release of carbon was about the same rate as decomposition signifying a quick release from the leaf litter. This was because the rate of C release effectively indicates the amount of litter used by micro-organisms in relation to the initial litter quality (Hossain *et al.,* 2014). At 48 WALP the total release of organic carbon or organic matter was approximately 91%.

This study has shown that the species has a high leaf litter decomposition rate. In 2 months (8 weeks), the leaf litter decomposed to half of its original mass. The decomposition constant of 4.62 yr^{-1} revealed that nutrients in the leaf litter can be released into the soil within a year and the nutrient release of all nutrient elements ranged between 89 – 94.70%.

Table 5: Regression equation parameters observed and expected mass losses (% decomposition) of *A. floribunda* leaf litter

% Decomposition		Regression equation parameters			
Observed	Expected	Slope	Intercept	Constant	Correlation
48 Wk	48Wk	(b)	(a)	(c)	(r)
91.00 (0.27 % day^{-1})	88.00 (0.26 % day^{-1})	28.83	2.94	0.04	0.96

Table 6: Initial Nutrient Content of A. floribunda Leaf Litter

Nutrient element	Amount (%)
Nitrogen	1.51
Phosphorus	0.38
Potassium	0.58
Calcium	2.16
Magnesium	0.72
Organic carbon	16.00
Organic Matter	27.55
C:N	10.60

Table 7: Cumulative nutrient release of leaf litter of *A. floribunda*

	Nutrient Elements (%)					
WALP	N	P	K	Ca	Mg	Org. C
4	50.53	12.00	31.20	47.49	53.10	37.94
8	58.16	38.20	57.40	52.98	56.00	66.29
12	70.18	45.50	69.40	67.93	60.40	59.59
16	79.67	62.20	71.90	77.44	74.20	68.79
20	74.77	73.50	76.30	81.59	74.80	76.76
24	80.52	78.80	85.20	80.74	84.70	80.56
28	87.06	85.90	81.90	88.22	90.10	78.47
32	92.60	92.20	90.60	83.43	79.20	91.31
36	95.30	95.50	93.10	88.63	81.50	95.34
40	97.33	96.30	94.30	91.88	85.10	95.43
44	87.79	93.00	91.20	90.79	90.30	90.41
48	89.20	94.70	93.70	89.69	89.00	91.31
LSD(P<0.05)	7.83	13.64	10.26	8.46	14.20	10.09

Correlation between decomposition rate and nutrient release

The cumulative release of nutrient elements from the leaf litter of *A. floribunda* and the decomposition rate had correlation values close to one. There was a positive correlation between cumulative decomposition rate and the release of all nutrient elements in the leaf litter (Table 8). The positive correlation between decomposition rate and nutrient release was in accordance with the findings of Bragazza and Freeman (2007) who indicated that as decomposition rate increased nutrient release also increased. Contrarily, Mahari (2014) reported a positive correlation between the release of K and mass loss in the three species studied, while the N and P release were significantly correlated with mass loss in only one species. These results suggest that the influence of litter mass loss on nutrient release patterns depends on the species and nutrient type.

Table 8: Correlation between decomposition rate and nutrient release

Nutrient Element	Decomposition rate
N	0.929**
P	0.983**
K	0.956**
Ca	0.933**
Mg	0.852**
Org. C	0.950**
Org. M	0.950**

** highly significant

Conclusion

The comparatively high relative decay rates of the leaf litter of *A. floribunda* and the subsequent nutrient inputs to the soil are useful for fast growing arable crops. The leaf litter could be used as organic manure for soil fertility restoration and improved growth and yield of arable crops. The humic materials formed from the leaf litter have colloidal properties and its capacity to hold and exchange basic cations could be high, with crop yield enhanced. Leaf litter of *A. floribunda* could also be used as mulch for weed and soil erosion control since the litter half-lives and full-lives are enough periods for weed control and the reduction of soil erosion thereby enhancing resilience to climate change in the farming systems in the humid rain forests of Nigeria.

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