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Effects of climatic variations on leaf litter production in *A. floribunda* agroforestry system in South-East Nigeria

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ABSTRACT

Field experiment was conducted between 2016 and 2018 at Forestry Research Institute of Nigeria (FRIN), Humid Forest Research Station, Umuahia, South-east Nigeria, to study litter production and climatic influence in *Allanblackia floribunda* (oliv) agroforestry system. The experiment was laid out in a randomized complete block design (RCBD) with three replications. Litter trays were used for monthly collection of leaf litter. Results indicated that soil chemical properties namely pH (H_2O), organic matter, total nitrogen and potassium increased with tree age from 4.8%, 1.3%, 0.07% and 0.07 Cmol/kg respectively in 2016 to 5.8 %, 3.2%, 0.30% and 0.1 Cmol/kg respectively in 2017. The dry season months of November, December, January and February gave significantly higher leaf litterfall (23.76 – 43.50 kg/ha in 2016/17 and 34.75 – 151.22kg /ha in 2017/18) than the rainy season months of April to October (4.96 – 14.53 kg/ha in 2016/2017 and 8.81 – 17.96 kg/ha in 2017/2018) cropping seasons. Leaf litter production positively and significantly correlated with maximum temperature (r = 0.60*) and (r = 0.70*) and negatively correlated with rainfall (r = -0.74**) and (r = -0.60*) and relative humidity (r = -0.86**) and (r = -0.79**) for 2017 and 2018 respectively, with a bimodal pattern showing leaf litter peak production in January and December. The high production of leaf litter during the dry season served as a protective cover for the soil against the scorching heat of the dry season sun.

1.0. Introduction

Allanblackia floribunda is a dioecious multipurpose tree which belongs to the family *Clusiaceae or Guttiferae* (Buss and Tissari, 2010). It is an evergreen tree that grows mainly in tropical rainforests but is also found in cultivated farmland areas. The genus *Allanblackia* consists of nine species found in the equatorial rainforests of West, East and Central African regions extending from Sierra Leone to Tanzania (Pye-Smith, 2009). Three of the nine species (*A. stuhlmannii, A. floribunda and A. parviflora*) have known importance in food (margarine) and cosmetic (soap and detergent) industries. Out of the three species of importance, *A. floribunda* is grown in Nigeria and has seed that is rich in edible oil, with some healthy physicochemical characteristics in food production that gives it an edge over other oils (Folarin *et al* 2017; Crockett, 2015). Despite the importance of this tree species, little is known about its contribution to soil fertility regeneration through leaf litter fall and production at different seasons in Nigeria.

Litter on the floor of forest comprises leaves, flowers, dropped fruits, dead twigs and bark (Ifo and Nwango, 2011). Coletano *et al*., (2011) reported that leaf litter is the key element of litterfall under several restoration measures of tropical forest in Costa Rica**.** Bisht *et al.,* (2014) observed that leaf litter contributed about 75 – 79 % of the entire litter in the forests of the North-west

Himalaya.

Litter fall is a vital source of nutrients and the main pathway through which nutrients and organic matter are released to the outer layer of the soil (Chandraa *et al.,* 2015). A portion of nutrients which are assimilated by plants for their growth and development is accumulated in plant body and a substantial amount of these nutrients is returned to the soil through litter decomposition. Leaf litter is the primary and quickest source of organic matter and nutrient to the soil compared to other litter types (Hasanuzzaman and Hossain, 2014). The collective and consecutive process of litter fall, its decomposition and subsequent mineralization are essential in sustaining a dynamic ecosystem. Litter of forest floor helps in controlling soil erosion, runoff and increases the rates of percolation as well as nutrient taken up by the tree which is held in the green leaves (Saha *et al*., 2016).

Litterfall in forest ecosystem varies in quantity and quality (Indriyanto, 2009) and is determined by climatic conditions, species composition and successional stage in its development (Haase, 1999). Guoyi *et al.* (2007) noted that litter production is closely related to successional stages and growth pattern in a forest ecosystem. Annually, the mean litterfall of a mixed stand is usually higher than that of a monoculture stand (Qingkui *et al*. 2008). However, the pioneer forest had an annual mean litterfall that was low but rapidly increased over the years. That is annual litter production increased rapidly during stand development until canopy closes and then remained relatively constant over an extended period before decrease in old stands (Saha *et al.,* 2016; Celentano *et al.,* 2011). Toky and Singh (1993) noted that 4-year-old stands of *Leuceana latisiliqua* (Syn *L. leucocephala*) and *Eucalyptus tereticornis* had similar litter production rates of about 7.5 t ha^{-1} and 7.2 t ha^{-1} respectively. However, the similar values were twice the production rate of *Acacia nilotica.* The quantities of litter in 8-year old stands of *L. latisiliqua, E. tereticornis* and *A. nilotica* were 11.5 t ha^{-1}, 9.1 t ha^{-1} and 5.4 t ha^{-1} respectively (Toky and Singh 1993). Kuruvilla *et al.* (2016) reported that the entire litter production in a year for *Munrochloa ritcheyi,* a native bamboo of Western Ghats, India was 2.842 t ha-1 year-1. Thus, litter production increases overtime (years).

Natural occurrences in forest, such as fire, wind and hurricanes significantly influence litterfall. Among these factors, climate plays a principal role in leaf litter production (Lopes *et al.,* 2015). Leaf abscission and senescence are also other major factors that facilitate leaf litterfall (Triadiati *et al.,* 2011). Wind may have its greatest effect only in the final stages of senescence. The distribution of leaf litter on the floor of the forest can differ due to slope and elevation, canopy cover, topography, fire and flood (Triadiati *et al*., 2011; Celetano *et al*., 2011; Xu and Hirata, 2002). Flood can remove about 75% of standing litter accumulation on the floor of the forest prior to flooding (Clarke and Alloway, 1996)

Litterfall accumulation on the floor of the forest is continuous throughout the year in the tropics but is often characterized by seasonal peaks. In other words, litter production varies with climatic conditions. The pattern of litter accumulation due to seasonal changes are similar for most tree species where peak periods are obtained in the dry period of the year (Abugre *et al.,* 2011). The increase in the period of drought, is because of physiological reaction to dry weather condition. These factors in addition to lower night temperatures which occur throughout the dry season are known to stimulate abscisic acid synthesis in plant leaf which in turn stimulates leaf senescence (Dawoe *et al.,* 2010). Kuruvilla *et al*., (2016) reported a triphasic pattern of litter deposition with a significant peak in February and two small peaks in May and December. The major peak coincided with natural senescence of leaves induced by temperature and/or moisture stress in the region. In the tropics, Abugre *et al* (2011) observed peak litter production for *Jatropha curcas* in Ghana in the dry season. Nzegbule and Mbakwe (2001) in Nigeria, recorded the peak period of litterfall of *Treculia africana* in the months of February and March, while in Costa Rica peak period of litter fall was recorded in the drier months of January and March (Celentano *et al.,* 2011). Similarly, peak periods of litter production in the temperate region are recorded during summer. Saha *et al*., (2016) and Bisht *et al.,* (2013) noted a marked seasonal variation in the quantity of litterfall, with litter production being higher during summer than winter. These peak periods correspond with the months with the lowest soil moisture.

The objectives of this study were to evaluate the rate of leaf litter production and climatic influence on *Allanblackia floribunda* leaf litter.

2.0. Materials and Method

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^o 34' N and longitude 7^o 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 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).

It is situated on the coastal plain geographical zone of South-Eastern Nigeria (Ujoh *et al*., 2011) and is dominated by a tropical rainforest vegetation (Ochege and Okpala-Okaka, 2017). The area is drained by Imo River and its tributaries flow in a southerly direction and empty into the Atlantic Ocean (Ukandu *et al*., 2011).

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).

Composite soil samples were collected randomly with an auger from the top 20cm soil depth in the experimental site. The samples were bulked, air dried and sieved with a 2 mm sieve and analyzed for physical and chemical properties in the laboratory.

Particle size analysis was done by the hydrometer method. Soil pH was measured in 1 : 25 soil : water suspension using glass electrode pH meter. Organic carbon was determined by wet dichromate oxidation method (Nelson and Sommers, 1982). Organic matter content was obtained by multiplying organic carbon values by 1.724 (Broadbent, 1965). Total nitrogen was determined in a kjeldahl apparatus (Bremner and Mulvaney, 1982); available phosphorus was extracted in Bray and Kurtz, No. 1 solution described by Olsen and Sommers (1982) and its concentration measured by the Vanado-molybilate blue colour method (Murphy and Riley, 1962); exchange bases (Ca, Mg, K and Na) were extracted with one normal neutral ammonium acetate solution (IN NH_4OAc at Ph 7.0) as described by Thomas (1982). Exchangeable K and Na concentrations in the extract were read on an EE2 flame photometer while Ca and Mg concentrations were read in Atomic Absorption Spectrophotometer (AAS).

The experiment was laid out in a randomised complete block design (RCBD) with three replications. There were two treatments namely Time (months of the year) and quantity of leaf litterfall. The *Allanblackia* plot size was 20 m x 10 m (200 m^2). The trees (*Allanblackia*) were spaced 3 m x 3 m to give a plant population of 1111 plants / ha in a north-south orientation. The trees were two years old in 2016 and three years old in 2017. In the 2016/2017 and 2017/2018 experiments, nine randomly positioned 1m x 1m litter trays were used. Each tray had a plastic mesh (2 mm) base and was raised on four legs which elevated the base to a height of 20 cm from the ground. Three litter trays were placed in each of the 10 m by 20 m blocks (200 m^2). Leaf litter was collected separately from each litter tray and placed in paper bags every 27th day of the month.

The monthly collected litter was oven dried at 70^0 C for 48 hours in the laboratory. The oven-dried litter was weighed to obtain the total litter production for each month. Data collected were subjected to analysis of variance (ANOVA) and means separated using Genstat 3 discovery edition (Genstat, 2007).

3.0. Results and Discussion

3.1. Result

3.1.1. Soil properties and meteorological data of the study area

The soil physical and chemical properties of the study area presented in Table 1 shows that the sand , silt and clay fractions was 71.04, 12.73 and 16.23 in 2016 while in 2017, the particle size distributions were 73.6, 9.7 and 16.7 for sand, silt and clay fractions, respectively. The experimental site was texturally sandy loam and acidic, with a low pH of 4.8 in 2016 but high pH of 5.8 in 2017 in the agroforestry site (Table 1). Soil nitrogen (0.07%) and organic matter (1.30%) were low in 2016 but, high (0.30 and 3.16%) in 2017 respectively. The soil was high in phosphorus (35.97 and 20.85mg/kg) but low in potassium (0.07 Cmol kg^{-1}) in both years.

Table 2 shows the annual rainfall which were 2322.7mm in 2016 and 2079.8mm in 2017, showing a decline in 2017. The rainfall pattern was bimodal with a peak in June and August in 2016 and July and September in 2017. Relative humidity at 0900 hrs was lowest in January (50 – 68%) and highest in July (88 – 89%), with lowest sunshine hours occurring in July (3.2 – 3.9 hrs). The mean maximum (31.6 and 32.1^{o}C) and minimum (23.9 and 24.2^{o}C) temperatures were similar in both years.

Table 1: Soil physical and chemical properties of the study area 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
Exchageable Acidity (Cmol kg^{-1})	1.25	0.4
ECEC (Cmol kg^{-1})	4.08	7.86
Base Saturation	68.71	94.79

Table 2: Meteorological data of experimental site at Forestry Research Institute of Nigeria, Umuahia.

Meteorological Factor	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total mean
2016													
Monthly Rainfall (mm)	0	0	257.7	129.3	278.4	354.1	268.7	396.2	312.6	273.4	45	7.3	193.56
Number of rain days	0	0	10	8	16	16	15	22	15	7	2	1	9.33
Max. Temperature (^oC)	33.6	35.6	32.7	33.1	32.3	29.2	28.6	28.8	29.8.8	30.8	32.3	32.1	31.74
Min. Temperature (^oC)	22.6	23.8	24.6	24.7	24.9	23.1	24.1	24.4	23.3	23.7	23.9	24.1	23.93
Relative humidity (%)	50	62	80	79	82	85	89	89	86	80	83	71	78.00
Sunshine (hrs)	7	4.7	4.4	5.1	5.4	4.7	3.9	3.4	6.2	5.8	7.4	7.4	5.45
2017													
Monthly Rainfall (mm)	51	0	76.7	188.3	134.2	298.1	493.9	222.4	400	184.2	31	0	173.32
Number of rain days	2	0	5	8	11	18	21	17	15	15	6	0	9.83
Max. Temperature (^oC)	33.3	34.8	34.9	33.1	31.9	31.6	29.6	30.6	29.7	30.4	32	33.6	32.13
Min. Temperature (^oC)	23.4	24.6	24.6	24.2	23.7	23.5	23.3	23.1	29.7	23.6	23.6	23.5	24.23
Relative humidity (900)	68	70	76	79	82	85	88	84	85	85	82	71	79.58
Sunshine (hrs)	5.7	6.4	7.9	6.3	7	5.8	3.2	4.6	3.5	4.7	6.4	7.2	5.73

Source: NRCRI (2018)

Leaf litterfall of *A. floribunda*

The leaf litter production of *A. floribunda* for a period of two cropping seasons 2016/2017 and 2017/2018 are presented in Table 3. Mean annual leaf litter production was 220.18kg/ha in 2016/2017 and 279kg/ha in 2017/2018 cropping season. The month of January had significantly the highest leaf litterfall (43.5kg/ha) in 2016/2017. However, in 2017/2018, the months of January and February had statistically similar leaf litterfall (46 and 51kg/ha) which was significantly ($p < 0.05$) higher than that of the months of March – November. Leaf litterfall was higher in the dry season months when compared to the rainy season months in both years, the dry season months produced significantly ($p < 0.05$) more than twice the quantity of the rainy season months (Table 4). The dry season months of November – March produced 65% and 67% of the annual leaf litterfall in 2016/2017 and 2017/2018 respectively. Generally, leaf litter fall of *A. floribunda* was spread throughout the year, although the quantity of monthly collections was highly unequal. Total leaf litterfall had a bimodal distribution pattern with peaks in January and December.

Leaf litterfall of *A. floribunda* correlated ($p< 0.05$) positively and significantly with maximum temperature and negatively correlated with rainfall and relative humidity during the two years of study (Table 5). There was no significant correlation between sunshine hours and minimum temperature in the leaf litterfall of *A. floribunda.*

Table 3: Mean monthly leaf litter production of Allanblackia floribunda

Time (months)	2016/2017 Leaf litterfall (kg/ha)	2017/2018 Leaf litterfall (kg/ha)
August	4.96	11.92
September	11.98	14.17
October	13.22	15.30
November	23.76	34.75
December	26.45	39.81
January	43.50	51.22
February	36.74	45.96
March	12.72	13.84
April	14.10	17.96
May	14.53	14.37
June	10.53	8.81
July	7.69	10.89
Total annual leaf litterfall	220.18	279.00
Mean annual leaf litterfall	18.35	23,25
LSD (P < 0.05)	5.33	8.17

Table 4: Seasonal variation of leaf litter production of Allanblackia floribunda

Season	Leaf litterfall (kg/ha)	Number	Standard error mean
2016/2017			
Wet	11.00	21.00	0.97
Dry	28.03	15.00	2.89
2017/2018			
Wet	13.35	21.00	1.11
Dry	37.12	15.00	1.56
Probability 0.000***			

Table 5: Correlation of leaf litter production of A. floribunda with some climatic variables.

Climatic variables	Leaf litter production	
	2017	2018
Rainfall	-0.74**	-0.60*
Relative humidity		
@900	-0.86**	-0.79**
@1500	-0.84**	-0.90**
Sunshine hours	0.32	0.24
Maximum temperature	0.60*	0.70*
Minimum temperature	0.07	0.01

Discussion

Generally, the impact of the leaf litter which served as mulch material on the soil was such that it increased pH (H_2O) from 4.8 in 2016 to 5.8 in 2017, organic matter from 1.3 to 3.2%, nitrogen from 0.07 in 2016 to 0.3% in 2017 and Potassium from 0.07 in 2016 to 0.10 Cmol/kg in 2017. Amalu and Usuah, (2014) had reported that dry organic mulch increased soil organic carbon content, total nitrogen and moisture content, reduced soil temperatures and improved cocoyam yields.

Leaf litterfall varies according to habit of the tree species, ~~stand~~ age of tree, soil fertility and climatic conditions (Tangjang *et al.,* 2015; Ifo and Nwango, 2011; Kohler *et al.,* 2008). The mean annual litter production of *A. floribunda* was 220 kg/ha/yr in 2017/2017 and 279 kg/ha/yr in 2017/2018 cropping seasons. These values could be as a result of the age of trees. The tree age is an important factor affecting litterfall, which increases with the stand age (Celentano *et al*., 2011). The values obtained for litterfall were low when compared to leaf litter production of 6228.33 kg/ha/yr from 18 years old *Entandrophragma cyclindricum* in south-south Nigeria reported by Olubunmi-Koyejo *et al.,* (2016).

In south-western Nigeria, *Leucaena leucocephala* (N-fixing legume trees) of similar age as was the case of this study, had mean annual leaf litter production of 7300 kg ha^{-1} y^{-1} (Salako and Tian 2001). The large difference reported by various workers could be due to differences in tree species. Tree species is an important factor that affects leaf litterfall. Celentano *et al.,* (2011) observed large variation in the litter production of the different species studied. In a natural tropical forest in Congo, Goma-Tchimbakala and Bernhard-Reversat (2006) reported that litterfall of *Terminalia superba* was controlled by stand basal area, age structure, stem volume, latitude, season and climatic factor.

The bimodal monthly leaf litter production pattern of *A. floribunda* agrees with the findings of Olubunmi-Koyejo *et al*., (2016) and Okeke and Omaliko (1992) who observed a bimodal litterfall for *Entandrophragma cylindricum* plantation and *Dactyledenia bacteri bush* fallow respectively. In the present investigation, leaf litterfall was generally higher in the dry season with bimodal peaks in January and December. Qingkui *et al*., (2008) in southern China similarly observed peak periods of litterfall during the cool and dry periods (November – March). Nzegbule and Mbakwe (2001) and Yang *et al*., (2003) also reported high litter production in the dry season months.

However, the bimodal pattern of litterfall is contrary to the findings of Gawali (2014) who observed a unimodal litterfall pattern for *Ceiba pentandra* in Eastern India and Norgrove and Hauser (2000) who also reported a unimodal litterfall with *Terminalia ivorensis* plantations in Cameroon. In the Lama Forest of Cotonou litterfall follows a unimodal distribution pattern (Guendehou *et al.,* 2014). Kuruvilla *et al.,* (2016) reported a trimodal pattern of litterfall with a major peak in February and two minor peaks in May and December. The distribution pattern of litterfall are unimodal, bimodal or irregular. These patterns depend on the ecosystem and tree species. Different ecosystems have different pattern of litterfall distribution while different tree species in the same ecosystem may have different distribution pattern.

The positive correlation of *A. floribunda* leaf litter with temperature and negative correlation with rainfall and relative humidity correspond with the investigation of Gawali (2014) and stress the impact of the dry season in litter production of evergreen woody species. In evergreen tree species litterfall increases in the dry months and decreases in the raining months. *A. floribunda* leaf litterfall followed the same pattern with peak production in the dry months of January and December. This is in agreement with the observations of Gawali (2014); Guendenhou *et al.,* (2014); Nzegbule and Ogbonna (2008); Valenti *et al*., 2008; Norgrove and Hauser (2000) Okeke and Omaliko (1994) who observed increased and low leaf litterfall rates during the dry season and rainy season, respectively. In south eastern

Nigeria the dry season months are periods of intensive water stress, low soil moisture, high temperature and low relative humidity. These features explain the reason for maximum leaf litterfall during the dry season. Environmental parameters and physiological factors have been reported to be the cause of seasonal variation in litterfall (Ndakara *et al*., 2011; Ifo and Nganga 2011). In the dry season, the physiological response to drought and low humidity in combination with low night temperatures are known to stimulate abscisic acid synthesis in plant foliage which, in turn, stimulate leaf senescence (Dawoe *et al.,* 2010; Yang *et al*., 2003).

Leaf litterfall was continuous throughout the year giving a protective cover to the soil all year round. Seasonal variation was observed in the leaf litter production pattern with highest production during the dry season. The continuous leaf litter production throughout the year and its subsequent decomposition and release of nutrient make *A. floribunda* leaf litter a good source of organic manure for soil fertility restoration.

The high production of leaf litter during the dry season will serve as a protective cover for the soil against the scorching heat of the dry season sun.

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