Decomposition and Nitrogen Release Patterns of *Parkia biglobosa* and *Albizia lebbeck* Leaves with Nitrogen Fertilizer for Maize Production in Sudan Savanna Alfisol of Nigeria

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Abstract

Biomass transfer or cultivation of leguminous trees has higher eco-friendly profiles for soil nutrients restoration especially nitrogen. The research is conducted on decomposition and nitrogen release patterns of *Parkia biglobosa* and *Albizia lebbeck* leaves with nitrogen fertilizer for maize production in sudan savannah alfisol of Nigeria. Data were analysed using (ANOVA). 56 % of N in the litter bag was released the first two weeks of biomass incubation and progressively increases weeks after planting. Decomposition rate constant (*KD*) ranged from 9.18 to 15.07 week^{-1} and the rates of plant residues was higher in *Albizia lebbeck* than *Parkia biglobosa* in both seasons. Nitrogen release rate constant (*KN*), ranging from 7.82 to 10.81 week^{-1} followed a similar pattern as the rate of decomposition with *Albizia lebbeck* releasing the highest amount of N followed by *Parkia lebbeck.* The rate of decomposition increased as week increased. Incorporation of *Albizia lebbeck* had significantly higher effect ($p < 0.05$) on growth parameter and yield component compared to *Parkia biglobosa*. The study concluded that *Albizia lebbeck* decomposed and mineralized faster for crop uptake under sudan savanna conditions. The study suggests that incorporation of *Albizia lebbeck* and up to 40 kg N ha^{-1} is a better combination for soil quality improvement and maize productivity in Makera, a semi-arid environment of Nigeria.

Keywords: Agroforestry trees, decomposition, leafy biomass, nitrogen release, fertilizer, maize production

1. Introduction

Lack of soil fertility restoring resources, soil erosion and unequal soil fertility management have been reported to contribute to soil fertility depletion in arid Africa (Bationo *et al.*, 2007; Vanlauwe and Giller, 2006). Leguminous trees that are nitrogen fixing trees are known to play complementary or alternative role as source of organic fertilizer and have the potential to sustain soil fertility (Giller, 2001; Snapp *et al.*, 2003; Adjei-Nsiah *et al.*, 2004).

Understanding decomposition and nutrient release or nitrogen mineralisation patterns of plant materials is an important first step to better managing organic inputs that are applied in agroforestry and other related land-use systems (Palm, 1995; Mafongoya *et al.*, 1998). These in turn depend to a large extent on chemical composition of plant tissues (Constantinides and Fownes, 1994). Initial N content of the biomass, C: N ratio, lignin content, lignin: N ratio, and polyphenol and its ratios with N and lignin have been shown to be important chemical qualities affecting the rate of decomposition and mineralization (Palm, 1995; Mafongoya *et al.*, 1998). Other factors that affect the rate of mineralization include climate, soil characteristics, and cultural practices such as the method of

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application of biomass, application of mineral fertilizers, and methods employed in soil tillage (Becker *et al.,* 1994b; Mugendi and Nair, 1997).

Residue decomposition rates and nutrient release or mineralisation patterns are controlled by both biotic and abiotic factors, the most important of which is residue quality (Vanlauwe *et al.,* 1996; Silver and Miya, 2001; Mungai and Motavalli, 2006; Teklay *et al.,* 2007). In order to manage the N mineralised from organic residues for crop uptake, there is need to understand decomposition and N mineralization patterns of the organic inputs in relation to their chemical composition. It has been established by various researchers that high lignin and polyphenol contents as well as high C: N ratios in leaves tend to slow down litter decomposition and nutrient release (Upadhyaya *et al.,* 2012; Constantinides and Fawnes, 1994; Handayanto *et al.,* 1994). Multipurpose trees (MPTs) which are low in polyphenols, can provide a rapid flush of N during mineralisation, and may therefore be a good choice for use with annual crops such as maize which requires large amounts of N in a short period of time. Nitrogen release by plant litter or biomass with high contents of polyphenols, lignin and C: N ratio is slow so that decomposition occurs over a long period of time (Palm, 1988). Inorganic fertilizers have gained popularity because, they are easy to manage, handle and apply. This is because it is easier to synchronize the release of nutrients and plant uptake with inorganic fertilizers than with manure (McLaughlin *et al.,* 2002). Chemical or mineral fertilizers have been reported to increase cereal rooting depth and root proliferation (Belford *et al.,* 1987; Brown, 1987). However, few smallholder farmers can afford mineral fertilizers, and those using fertilizer hardly use the recommended rates (Mugwe *et al*., 2009). Moreover, the little fertilizer available when added to the soil is often utilised with poor efficiency (Vanlauwe *et al*., 2010) due to environmental or soil-related factors (e.g leaching and volatilization of N) as well as management factors (e.g. poor timing or placement of fertilizer). On the other hand, the use of locally available manure is also limited by its low quality and quantity (Bationo and Waswa, 2011; Murwira *et al*., 2002; Sanginga and Woomer, 2009).

1. Methodology

Study Area

The study area was Makera, a village in Dutsin-ma Local Government Area of Katsina State. Dutsin-ma has an area of 527 km², altitude of 605 m, population of 169, 671 and lies within Latitude 12°27'18" N and Longitude 07°29'29"E and also found in the basement complex derived soils of Katsina State (Oguntoyinbo, 1993). The inhabitants of the area are farmers and they are predominantly Hausa and Fulani by tribe. Their main occupation is farming and animal rearing.

Experimental Design

This study was carried out at Makera, beside the Nursery Unit of the Federal University Dutsinma, Katsina State, Nigeria from 2014 and 2015 cropping seasons. Soil sample was collected from the fallow site of the farm. Physical and chemical properties of the soil were determined prior to the commencement of the experiment using standard methods. The experiments were laid in split-split plot design in 3 x 4 x 2 factorials with three replicates. The plot dimensions were 4 m x 3 m. Leafy biomass of *Albizia lebbeck* and *Parkia biglobosa* were pruned and incorporated fresh into the soil at the rate of 6 kg for each (5000 kg ha^{-1}) of the *Albizia lebbeck* and *Parkia biglobosa* biomass plots (B_1 and B_2) respectively and plots without incorporation of leafy biomass (B_0). The leafy biomass was incorporated into the soil for two cropping seasons (2014 and 2015). Four levels of N fertilizers were split applied as: N_0, 0 kg N ha^{-1} (control); N_1, 40 kg N ha^{-1}; N_2, 80 kg N ha^{-1}; N_3, 120 kg N ha^{-1} and half were applied at 2 weeks after planting (WAP). The remaining amount was applied 5 (WAP). The two varieties of maize used were (DMR- ESR- 7 (Yellow Maize) and 2009 EVAT (White Maize) were obtained from Katsina State Agricultural and Rural Development Authority (KTARDA). Two maize varieties were planted (two maize seeds were planted per hole, at equal depth and it was later thinned to one) by conventional spacing of 75 cm x 25 cm two weeks after incorporation of leafy biomass of *Albizia lebbeck* and *Parkia biglobosa* into the soil. Thinning was also done 2 (WAP) making the total plant population of 64 stands per plot.

Plant Tissue Analysis of Agroforestry Tree Species

Harvested leaves samples were air dried at the room temperature and ground to be analysed for initial contents of N, lignin and polyphenols. Total N was analysed by Macro-Kjeldahl digestion, followed by distillation and titration (Anderson and Ingram, 1993; Brandstreet, 1965). Lignin and cellulose were determined by the Acid Detergent Fibre (ADF) method as outlined in (Anderson and Ingram, 1993). The polyphenols was extracted in hot (80^0 C) 50 % aqueous methanol and determined calorimetrically with tannic acid as a standard measurement (Anderson and Ingram, 1993; Hagerman, 1988).

Decomposition Patterns

Fifty (50) grams of the tree-leafy biomass from all the treatments that received biomass application was placed in 1-mm mesh size litter bags and buried into the soil at a depth of about 15 cm at the time of maize planting (beginning of the season). One bag containing residues from each species were randomly removed from the soil in each plot at 2, 4, 6, 8 and 10 weeks after maize planting (WAP). The contents in the bags were cleaned with water, oven dried at 65^0 C to constant weight, and dry weights were recorded.

$Y = e–kt$, where Y is the percent remaining of initial weight of material at time t in weeks and k is the rate of decomposition/N release per week (rate constant). The k values were estimated using a nonlinear module in SAS (2000).

Nitrogen released (RLS) over time were calculated following the formula by Giashuddin *et al*. (1993).

$$\%\ \text{N RLS} = 100 - \%\ \text{of original N content remaining } (N_0) \text{ where,}$$

$$No = \frac{(\%\ \text{N a time } t)}{(\%\ \text{N at time } 0)} \times \%\ \text{of original weight remaining}$$

Statistical Analysis

Data were subjected to Analysis of Variance (ANOVA) using Statistical Analysis System (SAS, 2000) computer package at 5 % level of significance to determine differences in the treatment effect. The Duncan’s Multiple Range Test (Duncan, 1955) was used to separate means of differences among the treatments.

2. Results

Some Properties of the Soil before Planting

Soil physical and chemical properties were collected at the experimental site before the commencement of the experiment is presented in Table 1. The soil is low in total nitrogen and organic carbon with (0.04 % and 0.53 %) respectively. The soil distribution of exchangeable basic cations fallows this order: Ca>Mg>Na>K. Nitrate-nitrogen was higher than ammonia-nitrogen in the soil. The pH of the soil is acidic. The soil belongs to the textural class sandy loam.

Table 1: Soil physical-chemical properties before establishment of the experiment at Makera. 2014.

Soil properties	**Value**
Particle size (g/kg)	
Sand	88.6
Silt	4
Clay	7.4
Textural class	Sandy loam
Chemical properties	
pH	4.1
Organic carbon (%)	0.53
Total nitrogen (%)	0.04
NH_4^+N ($mgkg^{-1}$)	23.99
NO_3^-N($mgkg^{-1}$)	26.38
Available phosphorus (mg kg^{-1})	7.94
Exchangeable bases (C mol kg^{-1})	
Ca	6.25
Mg	1.01
K	0.2
Na	0.35
Al^+H	0.15
CEC	7.96

Chemical Composition of Leafy Biomass of the Albizia lebbeck and Parkia biglobosa

The plant materials showed slight variations between *Albizia lebbeck* and *Parkia biglobosa* in their chemical compositions during 2014 and 2015 cropping seasons. The leaves of *Albizia lebbeck* contained more N (leading to lower C: N ratio) than *Parkia biglobosa. Albizia lebbeck* had the highest concentration of lignin with mean value of 11.06, while *Parkia biglobosa* had highest concentration of C: N ratios with mean value of 6.30. The result in (Table 2) showed that *Parkia biglobosa* had low N and C contents compared with *Albizia lebbeck.*

Table 2: Initial chemical composition of the biomass of *Albizia* and *Parkia* plant species

Component	N %	C %	Lignin %	Polyphenol %	C: N
Albizia lebbeck					
2014	3.32a	18.62a	11.37a	0.65b	5.60b
2015	3.16a	18.65a	10.74a	0.48b	5.90b
Means	3.24a	18.64a	11.06a	0.57b	5.75b
Parkia biglobosa					
2014	2.85b	17.81b	8.35b	0.87a	6.20a
2015	2.44b	15.52b	8.13b	0.63a	6.40a
Means	2.65b	16.67b	8.24b	0.75a	6.30a

N= Nitrogen; C= Carbon; C:N= Carbon/N ratio
Means followed by the same letter(s) within the same column and treatment are not significantly different at 5 % level of probability using DMRT.

Decomposition Patterns of Plant Residues

50 g fresh weight of biomass was put inside litter bags for their decomposition. In general, there was a rapid loss of mass from the litter bags during the first two weeks after planting (2 WAP) for the two species (Figure 1) in this order *Albizia lebbeck* (38.2 g) < *Parkia biglobosa* (28.16 g) compared to initial weight of 50 g. At the end of four weeks after planting (4 WAP), *Albizia lebbeck*

had lost 42.19 g of its initial weight while 30.04 g of *Parkia biglobosa* had been decomposed. At 6 WAP, the rate of mass loss due to decomposition declined in both species. Even then, *Albizia lebbeck* continued to decompose faster compared with *Parkia biglobosa*. The rate of decomposition increased thereafter.

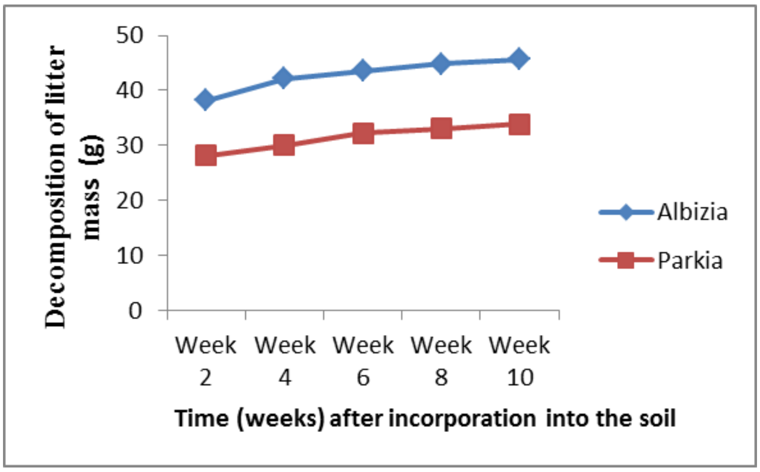

Figure 1: Loss weight of *Albizia* and *Parkia* leafy biomass over a period of 10 weeks

Decomposition Rates and N Release Patterns

The decomposition rate (*kD*) and N release rate (*N*) constants among *Albizia lebbeck* and *Parkia biglobosa* leafy biomass were considered significantly different from each other during the two seasons (Table 3). *Albizia lebbeck* biomass had the highest *kD* and *kN* rate constants, meaning that, it had the most rapid decomposition and N release rates followed by *Parkia biglobosa.*

Table 3: Decomposition rate *(kD)* and N release *(kN)* constants and their coefficient of determination *(R^2)* values for the different residues in the semi-arid of Nigeria

Season	Plant residue	*kD*	R^2	*kN*	R^2
2014	*Albizia*	15.07a	0.98	10.81a	0.99
	Parkia	9.18b	0.98	7.92b	0.99
2015	*Albizia*	15.00a	0.93	10.67a	0.98
	Parkia	10.69b	0.93	7.85b	0.98

Means followed by the same letter within a column in a particular season are not significantly different at 5 % level of probability. *kD* and *kN* values are *k*/week.

Dry matter yield

Consistently plots amended with *Albizia lebbeck* had significantly higher values of dry matter yield than other treatments at all sampling periods in 2014 and 2015. In 2014, the control treatment produced significantly lower values (15.1 kg ha^{-1}, 49 kg ha^{-1}, 66.9 kg N ha^{-1}, 87 kg N ha^{-1}) of dry matter than in plots supplied with nitrogen. Among the nitrogen treated plots the values were mostly comparable but numerically higher with increase in N rate. In 2015, plots supplied with 120 kg N ha^{-1} had highly increasing values of dry matter at than other N treatments 6, 8 and 10 WAP. There was no significant difference among varieties in 2014, while at 8 and 10 WAP, 2009 EVAT had significantly higher values (96.1 kg ha^{-1}, 132.3 kg ha^{-1}) of dry matter in 2015 (Table 4).

Table 4: Influence of biomass and nitrogen rate on dry matter yield per plant (g) of two maize varieties in 2014 and 2015

	Dry matter yield per plant							
	2014				2015			
Treatment	4 WAP	6 WAP	8 WAP	10 WAP	4 WAP	6 WAP	8 WAP	10 WAP
Biomass (B)								
Control	13.9c	58.0b	88.3b	123.5b	7.0a	60.9b	87.4b	130.8a
Albizia	21.9a	81.3a	116.1a	157.8a	6.3a	83.4a	107.5a	127.0a
Parkia	18.7b	67.3ab	93.9b	136.5ab	5.8a	41.5c	65.9c	94.5b
SE±	1.09	6.42	8.48	12.63	0.57	4.95	6.96	8.79
Nitrogen(N)Kg ha^{-1}								
0	15.1c	49.0b	66.9b	87.0b	6.2a	57.6b	81.5b	101.2b
40	16.7bc	75.0a	109.5a	140.7a	6.5a	52.6b	73.8b	106.3b
80	18.7ab	68.7ab	106.9a	155.7a	6.8a	55.9b	78.5b	125.0ab
120	22.0a	82.8a	114.5a	173.7a	6.1a	81.5a	113.8a	137.2a
SE±	1.36	7.04	8.97	12.49	0.71	6.5	8.15	10.32
Variety (V)								
DMR-ESR- 7	18.1a	68.0a	96.7a	145.2a	6.4a	57.2a	77.7b	102.6b
2009 EVAT	18.2a	69.8a	102.2a	133.3a	6.4a	66.6a	96.1a	132.3a
SE±	1.07	5.41	7.18	10.52	0.5	4.78	5.98	7.28
Interaction								
B x N	S*	S*	S*	S*	S*	S*	S*	S*
B x V	S*	S*	NS	S*	NS	S*	S*	S*
V x N	S*	S*	S*	S*	NS	S*	S*	S*

Means followed by the same letter(s) within the same column and treatment are not significantly different at 5 % level of probability using DMRT. WAP: Weeks after planting. S* Significant at 5 % level of probability. NS: Not significant.

Grain yield

Plots amended with *Albizia lebbeck* had significantly higher values (2097.2 kg ha^{-1}, 1666.7 kg ha^{-1}, 1881.9 kg ha^{-1}) of grain yield than other treatments in all cropping seasons and their combined means. In 2014, and combined means, the control treatment produced significantly lower values (833.3 kg ha^{-1}, 912 kg ha^{-1}) of grain yield than plots supplied with other N rates. No significant response to N rates on grain yield was observed in 2015. No significant difference was observed among varieties on grain yield in all cropping seasons and combined analysis (Table 5).

Table 5: Influence of biomass and nitrogen rate on grain yield (kg ha^{-1}) of two maize varieties in 2014, 2015

	Grain yield (kg ha-1)		
Treatment	2014	2015	Combined
Biomass (B)			
Control	1388.9b	1395.8ab	1392.4b
Albizia	2097.2a	1666.7a	1881.9a
Parkia	1413.2b	930.6b	1171.9b
SE±	210.71	162.49	136.18
Nitrogen (N) Kg ha-^{1}			
0	833.3b	990.7a	912.0b
40	1875.0a	1250.0a	1562.5a
80	1652.8a	1509.3a	1581.0a
120	2171.3a	1574.1a	1872.7a
SE±	221.33	201.49	152.62
Variety (V)			
DMR- ESR-7	1569.4a	1245.4a	1407.4a
2009 EVAT	1696.8a	1416.7a	1556.7a
SE±	180.69	147.99	117.56
Interaction			
B x N	S*	S*	S*
B x V	S*	S*	S*
V x N	S*	S*	S*

Means followed by the same letter(s) within the same column and treatment are not significantly different at 5 % level of probability using DMRT. WAP: Weeks after planting. S* Significant at 5 % level of probability. NS: Not significant.

3. Discussion

The soil is low in total nitrogen and organic carbon. The soil distribution of exchangeable basic cations fallows this order: Ca>Mg>Na>K. The pH of the soil is acidic. The soil belongs to the textural class sandy loam. *Parkia biglobosa* had low and N and C contents which had average of 2.65 % N and 16.67 % C and high C: N ratio which had average of 6.30. Soil is used to deplete soluble N and this hinders crops growth, structural development and resulted to low crop yield. This agrees with the report of (Giller, 2001) who stated that plant residues with high C: N ratio greater than 30:1 are likely to decompose slowly with initial net immobilization of N. It is noted that poor performance observed in plots incorporated with *Parkia biglobosa* was due to the low quality of the plant materials.

Performance in *Albizia lebbeck* plots was observed better because of the better quality materials embedded in it. Its materials contain higher average N content of 3.24 % N and 18.64 % C and lower average C: N ratio of 5.75 than *Parkia biglobosa* materials. According to (Giller and Wilson, 1991) who stated that plant residues with a smaller C: N (< 30:1) is liable to decompose more rapidly with a net mineralization of N after incorporation into the soil. Hence, N is rapidly released and made readily available for crops.

Consequently, the essence is to reduce if not complete withdrawal of inorganic N fertilizer for maize production; this is in agreement with (Olujobi and Oyun, 2013) who stated that supply of biomass from the leguminous tree and decomposing them with demand of the companion crop help in the release and uptake functions of limiting nutrients.

Nitrogen released from the two leguminous plants partly followed the same pattern as decomposition for the first two weeks. Over 56 % of N in the litter bag was released during the first two weeks of incubation for the two biomass species. Thereafter, the N content in the remaining un-decomposed litter generally increased with time for the two biomass types. The N release rate constants observed in this study indicates that *Albizia lebbeck* and *Parkia biglobosa* soil-incorporated biomass released up to 56 % of N into the soil after two to four (2 - 4 WAP) of incorporation and this also helped to boost the amount of mineral-N found in the soil in those treatments that received them.

The differences in decomposition and N release between biomass of *Albizia lebbeck* and *Parkia biglobosa* tree species could be interpreted by the amount of initial N concentration and C: N ratios contained in the tissue of these plant materials. Meanwhile, *Albizia lebbeck* leafy biomass that had significantly higher N concentration and lower C: N ratio than *Parkia biglobosa* decomposed and released N faster than *Parkia biglobosa* over the entire 10 weeks study period which is in agreement with the results of others that N content and C: N ratio serve as relevant bases for decomposition and N release study (Mugendi and Nair, 1997). It is noted that *Parkia biglobosa* contain high level of polyphenol which is known to have been confirmed and reported by other researcher to inhibit microbial activities, thereby slowing down the rate of decomposition and N release (Chesson, 1997; Mafongoya *et al.*, 1998). Lignin too also determines the rate of decomposition and its role in litter decay and nutrient release is widely reported in literature (Jama and Nair, 1996; Mafongoya *et al.*, 1998). Lignin is known for its highly resistant to microbial decomposition and its slowing down of N mineralization due to binding of N (Chesson, 1997). High lignin and polyphenol content in organic materials hamper the mineralization process due to their ability to bind proteins, thus determine the quality of organic materials to be decomposed by soil microbes (Handayanto *et al.*,1997). Therefore, it is important to note that decomposition and nutrient release are governed by the chemical composition of the plant materials.

The general performance of maize plants was higher in *Albizia lebbeck* amended plots, especially on total dry matter per plant and grain yield. Yield increases as nitrogen are released from leguminous crops (Peoples *et al.*, 1995; Mugendi *et al.*, 2000; Kang *et al.*, 1999). Incorporation of biomass often caused increased grain yield of maize than maize without incorporation of biomass (control). Application of N from 40 kg N ha^{-1} to 120 kg N ha^{-1} had an increasing effect on grain yield. This finding agree with that of Buah *et al.*, (2009) who reported that 120 kg N ha^{-1} currently produced the highest grain yield of maize in the Semi-Arid, Nigeria. Patel *et al.*, (2006) and El-Gizawy, (2009) also supported the fact that increase in N application will always lead to increase in grain yield of maize.

4. Conclusions

The N rates released from decomposed biomass of both *Albizia lebbeck* and *Parkia biglobosa* was around 56 % nitrogen between two to four weeks of planting (2 - 4 WAP). The differences in decomposition and nitrogen release patterns between *Albizia lebbeck* and *Parkia biglobosa* biomass was determined by the amount of initial N concentration and C: N ratios which are contained in the tissues of these plant materials. *Albizia lebbeck* leafy biomass decomposed and released nitrogen faster and was significantly higher in N concentration and lower C: N ratio than *Parkia biglobosa*. It was also noted that *Parkia biglobosa* contained high level of polyphenol, hence, slowed down the rate of decomposition and N release. Therefore, decomposition and nutrient release are governed by the chemical composition of the plant materials or residues. The use of biomass especially *Albizia lebbeck* alone can also give increase in grain yield but when it is combined with nitrogen fertilizer, it will produce better and higher grain yield. Therefore, incorporation of *Albizia lebbeck* with 120 kg N ha^{-1} produced highest grain yield in 2009 EVAT. Incorporation of *Albizia lebbeck* and up to 40 kg N ha^{-1} is a better combination for soil quality improvement and maize productivity in Makera, a semi-arid environment of Nigeria.

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