Journal of Tropical Resources and Sustainable Science

journal homepage: jtrss.org

Combined Effects of Organic and Inorganic Fertilizers on Maize for Sustainable Food Supply in Semi-Arid, Nigeria

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Received 02 Nov 2017
Accepted 26 May 2018
Online 30 June 2020

Keywords:
Agroforestry trees; decomposition; incorporation; leafy biomass; maize production; yield

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Abstract

Biomass transfer using fertiliser tree species is a more sustainable means for maintaining nutrient balances in maize based production systems. This research investigated the combined effects of incorporation of leafy biomass of fertilizer trees as organic fertilizer and urea as inorganic fertiliser for sustainable food production viz-a-viz maize-based crop in semi-arid, Nigeria. The experiment was laid out as 3 x 4 x 2 factorial in a split-split plot design with three replicates. Data were analysed using Analysis of Variance (ANOVA) at p =.05. *Albizia lebbeck* amended plots consistently had significantly higher values in 2014, 2015 and combined means (12.8 kg ha^{-1}, 13 kg ha^{-1}, 12.9 kg ha^{-1}) of cob length, (345.8 kg ha^{-1}, 311.8 kg ha^{-1}, 328.8 kg ha^{-1}) of grains per cob and grain yield (2097.3 kg ha^{-1}, 1667.7 kg ha^{-1}, 1881.9 kg ha^{-1}) throughout the cropping seasons and combined effect respectively compared to *Parkia biglobosa*. Positive significant correlation was experienced between the growth and yield components. Inclusion of nitrogen fertilizer and fertilizer trees improved the production of these maize varieties compared to control. It is therefore concluded that incorporation of *Albizia lebbeck* with up to 40 kg N ha^{-1} rate of nitrogen fertilizer into the soil improved its quality for better yield of both 2009 EVAT and DMR-ESR-7 maize varieties.

1. INTRODUCTION

Agroforestry practices have considerable potential to solve some of Africa's main land-use problems (Cooper et al., 1996) through provision of a wide range of tree products for domestic use or sale (Franzel et al., 2001). Agroforestry plays a significant role in increasing agricultural productivity by nutrient cycling, reducing soil erosion, and improving soil fertility and enhancing farm income compared to conventional crop production (Kang and Akinnifesi, 2000; Neupane and Thapa, 2001; Neupane et al., 2002).

Biomass transfer is essentially moving green leaves and twigs of fertiliser trees or shrubs from one location to another, usually in the wetlands to be used as green manure (Kuntashula et al., 2004). Recent studies (Kuntashula et al., 2004) have shown that biomass transfer using fertiliser tree species is a more sustainable means for maintaining nutrient balances in maize-based production systems. The advantage is that synchrony between nutrient release and crop uptake can be achieved with well-timed biomass transfer. The management factors that can be manipulated to achieve this are litter quality, rate of litter application, and method and time of litter application (Mafongoya et al., 1998).

Fertilizer trees improve soil for better productivity of maize yield and it components due to its N_2 fixation and recovery of leached nutrients (Akinnifesi et al., 2008). Legumes can also have other beneficial effects on crop yield as they can improve availability and uptake of nutrients such as phosphorus. Application of plant biomass from fertiliser trees as green manure can contribute to P availability, either directly by releasing tissue P during decomposition and mineralisation or indirectly by acting on chemical processes that regulate P adsorption-desorption reactions (Mweta et al., 2007).

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. 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. P fixation by sesquioxides, leaching and volatilization

eISSN Number: 2462-2389

of N etc.) 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 (Murwira et al., 2002; Sanginga and Woomer, 2009; Bationo and Waswa, 2011).

However, the supply of inorganic fertilizer is limited and where available, it is costly. Sanchez (2002) estimates the cost of inorganic fertilizers in Africa to be two to six times as much as it is in Europe, North America or Asia, and this cost is subsequently passed to the farmers. Although inorganic fertilizers would be the easiest way to overcome nutrient depletion (Sanchez, 2002), this product is not readily available for use by smallholder farmers. Even when they are available, their negative effects (such as erosion, leaching of nutrients etc.) on soil health and environment are of grievous consequences.

2. MATERIALS AND METHODS

2.1. Study area

Makera, a village in Dutsin-ma Local Government Area of Katsina State was selected as the study area based on land cover and human population. The study area has an area of 527 km², it is found within Latitude 12^{0}27’18” N and Longitude 07^{0}29’29” E and it has altitude of 605 m (Oguntoyinbo, 1983). The area receive an annual rainfall of 700 mm, which is spread from May to September. The mean annual temperatures range from 29-31^{o} C. the high temperature normally occurs in April/May and the lowest in December through February.

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2.2. Experimental design

The experiment was laid as 3 x 4 x 2 factorial in split-split plot design with three replicates. The gross plot size was 4 m x 3 m (12 m^2); while the net plot size was 4 m x 1.5 m (6 m^2). Each gross plot size was separated from each other by 1.5 m and 2.5 m in between the plots and replicates respectively (Figure 1). Leafy biomass of *A. lebbeck* and *P. biglobosa* at 6 kg each were pruned and incorporated fresh into the soil biomass plots (B_1 and B_2) 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}. The first was split applied at 2 weeks after planting (WAP), while the remaining was applied at 5 WAP. The two varieties of maize used (DMR- ESR- 7 (Yellow Maize) and 2009 EVAT (White Maize)) were obtained from Katsina State Agricultural and Rural Development Authority. Two maize seeds were planted per hole, at equal depth of 4 cm and it was later thinned to one by conventional spacing of 75 x 25 cm two weeks after incorporation of leafy biomass of *A. lebbeck* and *P. biglobosa* into the soil. The total plant population of 64 stands per plot.

2.3. Plant tissue analysis of agroforestry tree species

Samples of harvested leaves were air dried at room temperature and ground and analysed for initial contents of N, C, lignin and polyphenols. Total N was analysed by Macro-Kjeldahl digestion, followed by distillation and titration (Anderson and Ingram, 1993; Brandstreet, 1965). Lignin was determined by the Acid Detergent Fibre (ADF) method as outlined in Anderson and Ingram (1993). The polyphenol 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).

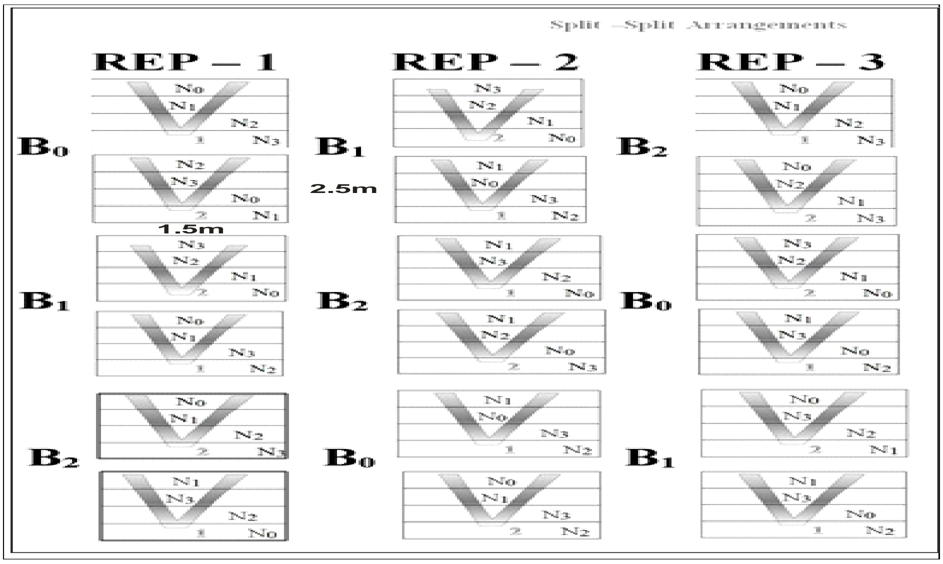
2.4. Data collection

Five maize plants were randomly selected within each of the net plots 4 m x 1.5 m (6 m^2) with a tag for periodic observations at 4, 6, 8 and 10 WAP during the crop growth cycle for pre- harvest data collection. At harvest, these same five tagged plants were used to obtain yield parameters; that is cob length, number of grains per cob and grain yield. The harvested cobs from the net plots were sun-dried, shelled, winnowed and the clean grains weighed. The total weight per plot was recorded and expressed in kilogram.

2.5. Data analysis

Data were subjected to Analysis of Variance (ANOVA) using Statistical Analysis System (SAS, 2003) 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 the means where significant differences exist among the treatments.

eISSN Number: 2462-2389



LEGEND

B_0= No incorporation of biomass (Control); **B_1**= Incorporation of *Albizia lebbeck* leafy biomass; **B_2**= Incorporation of *Parkia biglobosa* leafy biomass; **V_1**= DMR- ESR- 7 (Yellow Maize); **V_2**= 2009 EVAT (White Maize); **N_0**= No fertilizer (Control); **N_1**= 40 kg N ha^{-1}; **N_2**= 80 kg N ha^{-1}; **N_3**= 120 kg N ha^{-1}

Figure 1: Showing experimental design, layout and plot size demarcation

3. RESULTS AND DISCUSSION

3.1 Selected soil physical and chemical properties before planting

The physical and chemical properties of the soil was collected at the experimental site before the commencement of the experiment as presented in Table 1. The pH of the soil is acidic (4.10 and 4.21) in nature, low in total nitrogen and organic carbon with (0.40 and 0.46 gkg^{-1} and 5.30 and 5.46 gkg^{-1}) respectively. The soil belongs to the textural class sandy loam and acidic with pH as observed by Oyebamiji et al. (2017b).

Table 1: Soil physical and chemical properties before establishment of the experiment at Makera in 2014 and 2015

Soil properties	2014	2015
Particle size (gkg^{-1})		
Sand	88.60	87.25
Silt	4.00	3.96
Clay	7.40	7.35
Textural class	Sandy loam	Sandy loam
Chemical properties		
pH	4.10	4.21
Organic carbon (gkg^{-1})	5.30	5.46
Total nitrogen (gkg^{-1})	0.40	0.46
NH_4^+N ($mgkg^{-1}$)	23.99	24.78
NO_3^-N ($mgkg^{-1}$)	26.38	28.12
Available phosphorus (mg kg^{-1})	7.94	7.96

NH_4^+N: Ammonia-nitrogen; NO_3^-N: Nitrate-nitrogen

3.2. *Albizia lebbeck* and *Parkia biglobosa* leafy biomass chemical composition

The leaves of *Albizia* contained higher N (leading to lower C: N ratio) than *Parkia. Albizia* had higher concentration of lignin with mean value of 110.60, while *Parkia* had higher C: N ratios with mean value of 63.00. Table 2 revealed that, *Parkia* had lower N and C contents (Table 2). This implies that, *A. lebbeck* amended plots performed better than *P. biglobosa* due to considerable higher percent of nitrogen and carbon content ratio resident in it tissues. In comparison, *Parkia* had low N and C contents and high C: N ratio than *Albizia* as confirmed by Oyebamiji et al. (2017a). *A. lebbeck* plant residues decompose more rapidly than *P. biglobosa*. This could be possible because residue decomposition and nutrient release (mineralisation patterns) are controlled by both biotic and abiotic factors, and most importantly the residue quality (Mungai and Motavalli, 2006; Teklay et al., 2007).

Furthermore, high lignin and polyphenol content in organic materials prevent rapid mineralization process due to their ability to bind proteins, and hence, they determine the quality of organic materials to be decomposed by soil microbes (Handayanto et al., 1997). Therefore, decomposition and nutrient release are governed by the chemical composition of the plant materials.

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

Component	N (gkg^{-1})	C (gkg^{-1})	Lignin (gkg^{-1})	Polyphenol (gkg^{-1})	C: N
Albizia lebbeck					
2014	33.20a	186.20a	113.70a	6.50b	56.00b
2015	31.60a	186.50a	107.40a	4.80b	59.00b
Means	32.40a	186.40a	110.60a	5.70b	57.50b
Parkia biglobosa					
2014	28.50b	178.10b	83.50b	8.70a	62.00a
2015	24.40b	155.20b	81.30b	6.30a	64.00a
Means	26.50b	166.70b	82.40b	7.50a	63.00a

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 ($p > 0.05$)

3.3. Meteorological data of air temperature and total rainfall at Makera

There was even rainfall distribution in 2014 that brought about easy decomposition of the leafy biomass. In 2015, rainfall distribution was poorly and unevenly distributed, even though there were more rainfall than 2014 which adversely affected the crop production. However, the minimum temperature in 2015 was quite lower than that of 2014 (Table 3). The general performance of maize plants was higher in *A. lebbeck* amended plots on cob length per plant, number of grains per cob and grain yield due to even rainfall distribution in 2014 that brought about easy decomposition of the biomass, while in 2015, the rainfall distribution was poorly and unevenly distributed which adversely affected the crop performances.

3.4. Correlation on growth and yield components of maize

The result of the correlation analysis between grain yield, growth and yield components of maize in the combined means is shown in Table 4. The grain yield significantly and positively correlated ($p < 0.05$) with cob length, number of rows per cob, number of grains per cob, cob yield (kg ha^{-1}), 100-seed weight (g), grain and stover yield (kg ha^{-1}). Non-significant, positive and negative correlations exist with plant height at 8 WAP, total dry matter per plant at 8 WAP and total dry matter (kg ha^{-1}) respectively. Also, positive, negative and non-significant correlations exist with number of leaves per plant at 8 WAP and leaf area index at 8 WAP respectively (Table 4). Significant and positive correlations were observed between grain yield and yield components such as cob length, number of rows per cob, number of grains per cob, cob yield, 100-seed weight and stover yield. This could be as a result of the fact that these parameters are important yield determinants as reported by Jaliya (2006) and Sharifai (2012).

Table 3: Meteorological data showing monthly air temperature and total rainfall distribution at 10 days interval during 2014 and 2015 wet seasons at Makera (Katsina State)

	2014			2015		
Month	Temperature (^{0}C)		Rain fall	Temperature (^{0}C)		Rain fall
	Min	Max		Max	Min	
May						
1-10	360.5	253.7	21.6	403.6	244.6	NA
11-20	380.4	258.1	NA	404.3	268.9	NA
21-31	434.5	286.5	21.3	444.3	309.4	NA
June						
1-10	373.2	257.3	1.1	374.8	239.7	17.1
11-20	330.2	253.0	29.3	382.5	258.0	11.5
21-30	362.2	253.6	20.8	367.0	248.1	27.1
July						
1-10	335.9	294.3	26.3	357.3	243.7	30.2
11-20	339.8	245.3	42.6	333.5	225.4	39.1
21-31	358.5	261.9	89.2	343.5	234.4	86.5
August						
1-10	308.8	223.7	95.3	295.7	218.8	80.1
11-20	302.3	218.4	41.0	316.1	221.6	143.4
21-31	344.3	242.2	42.2	345.0	246.1	35.8
September						
1-10	315.3	217.7	17.2	315.6	216.9	45.0
11-20	326.9	224.2	41.8	324.9	223.5	14.2
21-30	333.3	225.7	16.9	335.1	218.0	16.6
October						
1-10	341.9	216.3	12.7	342.7	239.7	9.0
11-20	360.9	215.7	NA	366.5	241.5	NA
21-31	410.3	209.5	NA	402.8	239.8	NA

NA = Not Available Source = Nigerian Meteorological Agency (NIMA) Katsina State, Nigeria

3.5. Cob length

Albizia amended plots consistently had significantly higher values (12.8 kg ha^{-1}, 13 kg ha^{-1}, 12.9 kg ha^{-1}) cob length than other treatments at all sampling periods in 2014, 2015 and in their combined means. In 2014, 2015 and combined means, the control treatments

Table 4: Matrix of co-efficient of correlation between growth and yield parameters of maize in combined analysis

1	2	3	4	5	6	7	8	9	10	11	12	13
1	1											
2	0.805**	1										
3	-0.469**	-0.548**	1									
4	0.531**	0.427**	0.039 Ns	1								
5	0.469**	0.265**	0.184*	0.528**	1							
6	0.312**	0.245**	0.196*	0.419**	0.647**	1						
7	0.579**	0.340**	0.107 Ns	0.573**	0.935**	0.770**	1					
8	0.277**	0.106 Ns	0.398**	0.549**	0.753**	0.599**	0.758**	1				
9	0.475**	0.321**	0.080 Ns	0.457**	0.599**	0.460**	0.635**	0.609**	1			
10	0.546**	0.384**	0.063 Ns	0.618**	0.728**	0.579**	0.783**	0.834**	0.681**	1		
11	0.601**	0.478**	-0.098 Ns	0.592**	0.540**	0.437**	0.622**	0.464**	0.492**	0.556**	1	
12	0.652**	0.508**	-0.040 Ns	0.674**	0.709**	0.558**	0.781**	0.665**	0.621**	0.742**	0.902**	1
13	0.019 Ns	-0.055 Ns	0.177*	0.059 Ns	0.245**	0.167*	0.220**	0.328**	0.231*	0.464**	-0.211**	-0.109 Ns

*: Significant at 5 % level of probability. **: Significant at 1 % level of probability. Ns: Not significant.

1. Plant height at 8 WAP.
2. No. of leaves per plant at 8 WAP.
3. Leaf area index at 8 WAP. 2
4. Total dry matter per plant at 8 WAP.
5. Cob length.
6. No. of rows per cob.
7. No. of grains per cob.
8. Cob yield (kg ha-1).
9. 100 Seed weight (g).
10. Grain yield (kg ha-1)
11. Stover yield (kg ha-1).
12. Total dry matter (kg ha-1).
13. Harvest index.

produced significantly lower values (9.3 kg ha^{-1}, 11 kg ha^{-1}, 10.2 kg ha^{-1}) of cob length than in plots supplied with other nitrogen treatments.

The effect of variety on cob length revealed that influence of maize varieties was not significant on cob length in 2014 and in the combined means but was significant in 2015 where 2009 EVAT had significantly higher value (12.6 kg ha^{-1}) over DMR-ESR-7 (Table 5). The performance in terms of yield in biomass treated plots contributed to the increase in the amount of N fixed by the biomass and quantity of N derived from the decomposition of the incorporated biomass. The response of maize to nitrogen application agrees with Daudu (2004) and Cherr et al. (2006) that biomass and nitrogen fertilizer used has significant effect on maize growth.

3.6. Number of grains per cob

Albizia amended plots consistently had significantly higher number (345.8 kg ha^{-1}, 311.8 kg ha^{-1}, 328.8 kg ha^{-1}) of grains per cob than other treatments at all sampling periods in 2014, 2015 and in their combined means. The control treatments (plots without nitrogen) produced significant lower values (191.5 kg ha^{-1}, 243 kg ha^{-1}, 217.2 kg ha^{-1}) of number of grains per cob than other N treatments at all sampling periods in 2014, 2015 and in their combined means. Maize varieties had no significant effect on number of grains per cob in all sampling periods in 2014, 2015 and in their combined means (Table 6). The quantity of N derived from the decomposition of the incorporated biomass as well as the response of maize to nitrogen application agrees with Daudu (2004) and Cherr et al. (2006) that biomass used and fertilizer applied has significant effect on maize growth. Also, fertilizer application in 2014 improved the performance of number of grains per cob of the two maize varieties. Meanwhile, in 2015, the accumulation of nitrogen fertilizer in the soil made the maize crop to perform better at fertilizer application at 80 kg N ha^{-1} rate than 120 kg N ha^{-1}. However, there was no effect in nitrogen fertilizer application in the combined means.

Table 5: Influence of biomass and nitrogen rate on cob length plant^{-1} (cm) of two maize varieties in 2014 and 2015

	Cob length plant^{-1} (cm)		
Treatment	2014	2015	Combined
Biomass (B)			
Control	11.6b	12.1ab	11.8b
Albizia	12.8a	13.0a	12.9a
Parkia	12.0ab	10.8b	11.4b
SE±	0.51	0.47	0.35
Nitrogen (N) Kg ha-1			
0	9.3c	11.0b	10.2c
40	12.0b	11.8ab	11.9b
80	13.1ab	12.8a	12.9ab
120	14.1a	12.3ab	13.2a
SE±	0.43	0.58	0.37
Variety (V)			
DMR- ESR-7	12.3a	11.3b	11.8a
2009 EVAT	12.0a	12.6a	12.3a
SE±	0.43	0.41	0.30
Interaction			
B x N	S*	S*	S*
B x V	NS	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. S* Significant at 5 % level of probability. NS: Not significant. SE: Standard Error

Table 6: Influence of biomass and nitrogen rate on number of grains per cob of two maize varieties in 2014 and 2015

Number of grains cob^{-1}			
Treatment	2014	2015	Combined
Biomass (B)			
Control	272.7b	280.8ab	276.7b
Albizia	345.8a	311.8a	328.8a
Parkia	301.4b	242.7b	272.0b
SE±	20.62	17.42	13.80
Nitrogen (N) Kg ha-^{1}			
0	191.5c	243.0b	217.2b
40	313.1b	269.3ab	291.2a
80	345.2ab	320.0a	332.6a
120	376.7a	281.3ab	329.0a
SE±	18.42	21.39	14.81
Variety (V)			
DMR- ESR-7	302.3a	260.4a	281.4a
2009 EVAT	310.9a	296.4a	303.6a
SE±	17.46	15.33	11.69
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 significantlydifferent at 5 % level of probability using DMRT. S* Significant at 5 % level of probability. NS: Not significant. SE: Standard Error

3.7. Grain yield (kg ha^{-1})

Plots amended with *Albizia* 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 7). The performance in terms of grain yield in biomass treated plots and the response of maize to nitrogen application agrees with Daudu (2004) and Cherr et al. (2006) that biomass used and fertilizer application has significant effect on maize growth. Incorporation of *A. lebbeck* biomass to maize crop and application of nitrogen fertilizer up to 40 kg N ha^{-1} will have increasing effect on maize yield components. This fact was supported by Buah et al. (2009) findings, who reported that fertilizer application up to 40 kg N ha^{-1} but not more than 120 kg N ha^{-1} produce the highest grain yield of maize in the semi-arid of Nigeria.

Table 7: Influence of biomass and nitrogen rate on grain yield of two maize varieties in 2014 and 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. S* Significant at 5 % level of probability. NS: Not Significant. SE: Standard Error

4. CONCLUSION

A. lebbeck leafy biomass decomposed and released nitrogen faster than *P. biglobosa*. Incorporation of *A. lebbeck* into the soil improved soil for better grain yield. The use of biomass especially *A. lebbeck* alone increased grain yield but with combined effect of nitrogen fertilizer, produced better and higher yields. Therefore, incorporation of *A. 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 area of Nigeria.

ACKNOWLEDGEMENT

We acknowledged the notable contributions of Makera community for accommodating the conduct of this research in their area.

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