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NUTRIENT RELEASE AND LOSS FROM LEAFY BIOMASS OF TWO AGROFORESTRY TREE SPECIES THROUGH LEACHING UNDER LABORATORY CONDITIONS

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ABSTRACT

Leguminous tree species are organic base materials capable of replenishing soil fertility. Leguminous trees that fix nitrogen to the soil have not gained enough popularity in practice among farmers in Nigeria. Hence, this study evaluated nutrient release and loss from leafy biomass of two agroforestry tree species (*Albizia lebbeck* and *Senna siamea*) through leaching under laboratory conditions. Five grammes of fresh green biomass were pruned from Federal University Dutsin-Ma Arboretum. The pruned samples were weighed into 500 mL beaker and soaked in 250 mL water for different durations : 0, 24, 48, 72, 96, 120, and 144 h and repeated six times. Data were analyzed using One Way Analysis of Variance. Nitrogen (N) and organic carbon (OC) had significantly ($p \leq 0.05$) higher values (37.50 g/kg and 74.76 g/kg) in *A. lebbeck*; and its decomposition and nutrient release were faster than in *S. siamea*. However, *S. siamea* had lower values (69.30 g/kg) in lignin (L), (151.40 g/kg) in lignin to polyphenol ratio (L: PP), (17.60 g/kg) in lignin to nitrogen ratio (L: N), (18.70 g/kg) in lignin plus polyphenol to nitrogen ratio (L+PP): N and (121.60 g/kg) in cellulose that also encouraged it decomposition and nutrients release. About 50.66 % h^{-1} mass was lost through leaching in both species within the first 72 h. However, the mass loss was comparable in that *S. siamea* was higher than *A. lebbeck* in terms of mass loss In conclusion, these leafy biomass of agroforestry tree species tend to release nutrients when decomposed, butleaching of nutrients must be minimal for plant effective use. The green biomass of *S. siamea* and *A. lebbeck* have potential as organic soil fertility improvement materials for plant production. However, rate of nutrients leached in *A. lebbeck* leaves was less than in *S. siamea*.

Keywords: Biomass, decomposition, leguminous trees, nutrient potential, plant growth, soil amendment

INTRODUCTION

Introduction of leafy biomass as organic fertilizer using leguminous tree species has not gained enough popularity in Nigeria (Oyebamiji *et al.,* 2018a). Leguminous tree species are organic base materials capable of replenishing soil fertility and soil declination. However, the methods and applications of this leafy biomass are alien to quite a number of subsistence farmers (Oyebamiji *et al.,* 2017). As a practice, Nigerian farmers mainly use mineral fertilizers as supplements to improve soil fertility for crop productivity. Still, empirical studies have revealed that mineral fertilizers have the potential to cause ecosystem challenges in terms of disturbing their health status, environmental pollution, soil acidity, erosion, and invariably reduced soil micronutrients and microbial activities (David *et al.*, 2012). Hence, it is vital to transition from a chemical-based farming system to a more sustainable organic-based agricultural system that will improve soil quality and offer crop productivity at high returns and relatively low cost (Oyebamiji, 2018). Soil amendment with organic materials improves plant growth through efficient nutrient supply and promoting microbial population (Jacqueline *et al.,* 2012; Cercioglu, 2017; Page-Dumroese *et al.,* 2018; Singh *et al.,* 2023).

Leafy biomass decomposition of the leguminous tree species is an essential profile of soil nutrient restoration, especially nitrogen in the forest ecosystem and agroforestry in most tropical forests (Mensah, 2015). Leguminous tree species are the essential sources of soil nutrients that help in plant growth and development by increasing soil fertility through decomposing their biomass materials (Mensah, 2015). Decomposition provides essential soil nutrients for plant growth (Liu *et al.,* 2010). Decomposition also means the biological process that takes place in the soil, and during this process, organic matter releases mineral nutrients for the development and sustainability of plant growth. Micro and macro decomposers decompose fresh leafy biomass to make nutrients from nitrate available to plants (Adams and Angradi, 2007). Meanwhile, the inability to adequately restore soil fertility due to soil erosion and poor management culture has depleted soil fertility in sub-Saharan Africa (Adams and Angradi, 2007).

Therefore, understanding the decomposition and mineralization patterns of the two species will help improve and solve soil fertility problems (Palm *et al.,* 2006). The initial chemical components of the two leafy biomass are nitrogen (N), carbon (C), lignin (L), and polyphenol (PP) when the ratio of these elements is sufficient, especially the lignin and polyphenol ratio are important to determine nutrient release (Mafongoya *et al.,* 2000). Climate, soil characteristics, and cultural practices could also affect nutrient release of plant materials (Aleksandra *et al.,* 2020). The high lignin, polyphenol contents, and high C: N ratio in leaves slow down decomposition and mineralization, and vice-versa (Oyebamiji *et al.,* 2022). Leaf litter quality is key in determining the decomposition rate of litter (Zhang *et al.,* 2014). Organic carbon present in the leaf litter is known to be the decomposers' primary energy source. Hence, the decrease in the amount of debris is predicated on the efficiency of the decomposers (Liu, 2012; Giebelmann *et al.,* 2011). Therefore, decomposers' efficiency is also determined by litter quality, nutrient and water availability, and temperature (Hattenschwiler and Jorgensen, 2010). However, during the litter decomposition process, there are a series of changes in chemical composition in the litter as a result of possible structural and soluble compound degradations (Argao *et al.,* 2009).

The tropical soils usually experience a short-term rainfall regime with a lot of erosivity, affecting the loss of nutrients over time. Most of the nutrients leach away due to heavy rain with a lot of runoff water, which causes erosion, thereby washing away nutrients that are supposed to be helpful for both agricultural and forest-based crops (Oyebamiji *et al.,* 2017). Even though organic materials through leafy biomass decomposition are crucial to soil amendment strategies, the leaching of nutrients through moisture cannot be over-emphasized (Oyebamiji *et al.,* 2018b). Leaching is the downward movement of dissolved nutrients that could occur along the soil profile when water percolates (Clark *et al.,* 2003). Leaching also means the translocation of solutes (Moody, 2006) beyond the rooting zone. Buol *et al.* (2003) presented leaching as removing solutes entirely from the solum, a material loss from the soil profile. However, water content has exceeded the field capacity for draining, indicating that either rainfall or irrigation has gone beyond evapotranspiration. Therefore, the leached nutrients are temporarily lost but recycled by cultivating deep-rooted crops (Thakur and Kumar, 2020). It is interesting to know that when the solute leaches below the rooting zone, it will not be available for plant uptake and thereby cause a loss for the plant system (Saffigna and Philips, 2006). The primary nutrients are mostly vulnerable to leaching because of the weak adsorption capacity of both ammonium and potassium ions and nitrate's adsorption ability (Corley and Tinker, 2003). The leached nutrients are consistently far below the rooting zone. However, roots that grow deeper into the soil can assess nutrients quickly. In an area where intensive agriculture is in operation, contamination of underground water is possible. Hence, it hurts agricultural productivity and causes soil acidification (Al-Zarah, 2010; Marschner, 2012). It is important to note that negatively charged ions can be used by plants when nitrate, a negatively charged ion from a hydroxide ion is released to maintain electrical balance in the plant. But, if plants do not use nitrate, leaching is inevitable (Odiwe *et al.,* 2016).

After decomposition, the nutrients in the leafy biomass improve soil fertility as they are released. Meanwhile, the leaching of soluble components is also possible by microbial oxidation of intractable components (Hasanuzzaman and Mahmood, 2014). Romero *et al.* (2005) and Stephen *et al.* (2006) reported that the early leaching phase of leafy biomass decomposition usually lasts for a few weeks, while materials like carbon, nitrogen, and phosphorus are equally released to the environment as a result of the influence of the host soil decomposers (Zhangting *et al.,* 2021). However, in soil saturated by stagnant water, abiotic activities must be expedited (Stephen *et al.,* 2006). Nutrient loss through leaching is generally higher in humid areas than in arid regions (Shibabaw *et al.,* 2015). Soil macropores may increase nutrient leaching due to heavy rainfall and superficial fertilizer application (Kirsten *et al.,* 2019).

MATERIALS AND METHODS

Study Area

The study was carried out in Federal University of Dutsin-Ma Arboretum. The University is located 60 km along Katsina, Kankara road. The coordinate of the plant collection sites is 12º28'24" N and 07º29'0" E. The area receives an annual rainfall of 700 mm from May to September. The mean annual temperatures range from 29-31^{0} C. The high temperature occurs typically in April/May and the lowest in December through February (Tukur *et al.,* 2013; Oyebamiji *et al.,* 2018).

Sampling Procedure

A. lebbeck (L.) and *S. siamea* (Lam.) leafy biomass were randomly harvested from Federal University Dutsin-Ma Arboretum from five tree stands each (i.e., *A. lebbeck* and *S. siamea*). The pruning of these green biomass was in May 2019 before the advent of the rainy season when no leaching occurred since it is still the dry season. The leafy biomass was collected using litter bags in which five grams (5 g) of each sample from the two green biomass were immediately weighed into 500 mL beakers containing 250 mL of distilled water following the procedure of Mahmood *et al.* (2009).

Seventy-two samples of the two leafy biomass were prepared (i.e., 36 pieces each) and examined for the experiment. The replication of green biomass samples inside 500 mL beakers was carried out six (6) times at an interval of 0, 24, 48, 72, 96, 120, and 144 h, and the samples were rinsed in distilled water thoroughly after soaking. Then, representative samples of the leached water were analyzed in the laboratory to get results for total dissolved solids (TDS), pH, and suspended solids. The decomposed leafy biomass was air-dried at room temperature and weighed again to determine the mass loss rate (g). Furthermore, the air-dried decomposed biomass was ground and sieved using a 2 mm mesh size and then taken to the laboratory for chemical analysis using an atomic absorption spectrophotometer to measure the embedded nutrients content such as Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), and Sodium (Na) at the Chemistry Laboratory, Federal University Dutsin-Ma. The nutrients left in the leafy biomass and the leached water samples were analyzed and recorded, respectively.

Statistical Analysis

Mass loss and nutrient concentration in leached water samples and leafy biomass of each of the species were compared at different time intervals using One Way Analysis of Variance (ANOVA) using the Statistical Analysis System (SAS, 2015) computer package at a 5 % level of significance to determine differences among the treatments. The significant means were separated by the Duncan Multiple Range Test (DMRT) at five (5) percent level of probability (Duncan, 1955).

RESULTS

Chemical Composition of the Selected Leafy Biomass of Agroforestry

The higher nitrogen (N) had a significantly higher value (37.50 g/kg) and organic carbon (OC) with a substantially higher value (74.76 g/kg) from *A. lebbeck* leafy biomass, and this informed its capacity for rapid decomposition of its organic material. However, *S. siamea* was low in carbon to nitrogen ratio (C: N), lignin (L), lignin to polyphenol ratio (L: PP), lignin to nitrogen ratio (L: N), polyphenol to nitrogen ratio (PP: N), lignin plus polyphenol to nitrogen ratio (L+PP): N and cellulose (Table 1).

Concentration of Macro Nutrient of Leafy Biomass

Nutrient loss through leaching decreased throughout the different time intervals in both species of leafy biomass and across the selected macronutrients investigated, as presented in Table 2. Furthermore, the nutrient releasewas obviously and critically higher, as observed in both leafy biomass within 0-72 h across all the selected macronutrients. Nitrogen was significantly higher with different time intervals (0-144 h and 0-72 h) in both *A. lebbeck* and *S. siamea*. Nitrogen leaching was not significant in *A. lebbeck* from 0-144 h. However, there were higher significant values (37.50 g/kg, 28.00 g/kg, 25.80 g/kg, and 25.20 g/kg) of nitrogen from 0-72 h in *A. lebbeck*. Meanwhile, 36.00 g/kg, 29.80 g/kg, and 21.30 g/kg were the significant values of nitrogen leaching in *S. siamea* from between 0-72 h. The release of organic carbon and magnesium through leaching was significantly higher in *A. lebbeck* across the different time intervals (0-144 h). No significant difference (P>0.05) in the quantity of leached phosphorus among the different time intervals except at 0-24 h. Calcium was significantly higher in *S. siamea* than in *A. lebbeck* across the time intervals (0-144 h). Meanwhile, potassium was not significantly higher in both leafy biomasses, except in *S. siamea,* where there was no significant difference at time intervals between (0-144 h). However, sodium was significantly higher in both *A. lebbeck* and *S. siamea* (0-72 h and 0-48 h) respectively (Table 2).

Table 1: Chemical composition of the selected leafy biomass of agroforestry (g/kg)

Species	N	OC	C: N	L	PP	L: PP	L: N	PP: N	(L+PP): N	Cellulose
AL	37.50^{a}	74.76^{a}	199.40^{a}	155.80^{a}	2.40^{b}	542.90^{a}	41.50^{a}	130.70^{a}	42.20^{a}	173.30^{a}
SS	36.00^{a}	58.75^{b}	163.20^{b}	63.30^{b}	4.10^{a}	151.40^{b}	17.60^{b}	86.10^{b}	18.70^{b}	121.60^{b}

Means followed by the same letter(s) within the same column and treatment are not significantly different (P>0.05). N= Nitrogen, OC= Organic carbon, C:N= Carbon to nitrogen ratio, L: PP= Lignin to polyphenol ratio, L:N= Lignin to nitrogen ratio, PP:N= Polyphenol to nitrogen ratio, (L+PP):N= Lignin plus polyphenol to nitrogen ratio.

Table 2: Mean concentration of macronutrients released from the leafy biomass through leaching.

Species	Hours	Macronutrient contents						
		N (g/kg)	OC (g/kg)	P (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Na (mg/kg)
Albizia lebbeck	0	37.50^{a} ± 0.0052	74.76^{a} ± 0.0052	370.00^{b} ± 0.0052	6500.00^{b} ± 0.005	1050.00^{b} ± 0.0052	1850.00^{a} ± 0.005	480.00^{a} ± 0.0052
	24	28.00^{a} ± 0.0052	65.78^{a} ± 0.0052	320.50^{b} ± 0.0052	6416.07^{b} ± 0.005	880.00^{b} ± 0.0052	1500.00^{a} ± 0.005	370.00^{a} ± 0.0052
	48	25.80^{a} ± 0.0052	65.21^{a} ± 0.0052	305.00^{b} ± 0.0052	5780.33^{b} ± 0.005	860.17^{b} ± 0.0052	1400.00^{a} ± 0.005	354.67^{a} ± 0.0052
	72	25.20^{a} ± 0.0052	65.06^{a} ± 0.0052	270.00^{b} ± 0.0052	5320.50^{b} ± 0.005	840.00^{b} ± 0.0052	1249.83^{a} ± 0.005	310.00^{a} ± 0.0052
	96	23.20^{a} ± 0.0052	64.96^{a} ± 0.0052	208.83^{b} ± 0.0052	5300.00^{b} ± 0.005	540.17^{b} ± 0.0052	1210.00^{a} ± 0.005	296.67^{b} ± 0.0052
	120	18.20^{a} ± 0.0052	64.71^{a} ± 0.0052	185.00^{b} ± 0.0052	4250.00^{b} ± 0.005	480.00^{b} ± 0.0052	1170.00^{a} ± 0.005	270.00^{b} ± 0.0052
	144	17.10^{a} ± 0.0052	64.45^{a} ± 0.0052	182.00^{b} ± 0.0052	3699.83^{b} ± 0.005	370.00^{b} ± 0.0052	890.00^{a} ± 0.005	180.00^{b} ± 0.0052
Senna siamea	0	36.00^{a} ± 0.0052	58.75^{b} ± 0.0052	420.00^{a} ± 0.0052	8500.00^{a} ± 0.005	1450.00^{a} ± 0.0052	800.00^{b} ± 0.005	600.00^{a} ± 0.0052
	24	29.80^{a} ± 0.0052	58.64^{b} ± 0.0052	400.00^{a} ± 0.0052	8000.00^{a} ± 0.005	1270.17^{a} ± 0.0052	700.00^{b} ± 0.005	420.00^{a} ± 0.0052
	48	21.30^{a} ± 0.0052	58.52^{b} ± 0.0052	340.00^{b} ± 0.0052	5000.00^{b} ± 0.005	1200.00^{a} ± 0.0052	620.00^{b} ± 0.005	370.00^{a} ± 0.0052
	72	19.00^{a} ± 0.0052	57.92^{b} ± 0.0052	320.00^{b} ± 0.0052	2653.67^{b} ± 0.005	1175.00^{a} ± 0.0052	570.00^{b} ± 0.005	290.00^{b} ± 0.0052
	96	15.70^{b}± 0.0052	57.83^{b} ± 0.0052	282.33^{b} ± 0.0052	2000.00^{b} ± 0.005	1140.00^{a} ± 0.0052	410.00^{b} ± 0.005	200.00^{b} ± 0.0052
	120	15.50^{b} ± 0.0052	57.77^{b}± 0.0052	235.00^{b} ± 0.0052	1920.00^{b} ± 0.005	1135.00^{a} ± 0.0052	299.83^{b} ± 0.005	180.00^{b} ± 0.0052
	144	12.10^{b} ± 0.0052	57.51^{b} ± 0.0052	160.00^{b} ± 0.0052	1906.83^{b} ± 0.005	1120.00^{a} ± 0.0052	266.67^{b} ± 0.005	120.00^{b} ± 0.0052

Means followed by the same letter(s) within the same column and treatment are not significantly different (P>0.05). N= Nitrogen, OC= Organic carbon, P= Phosphorus, K= Potassium, Ca= Calcium, Mg= Magnessium, Na= Sodium

pH of leached water sample

A. lebbeck experienced a progressive pH increase in the leached water sample throughout the experiment (24-144 h). The implication is that *A. lebbeck* had the highest pH value (7.78) at 144 h and the lowest (6.88) at 24 h, respectively. Meanwhile, *S. siamea* had the highest pH value (6.43) at 72 h and the lowest (4.88) at 48 h. In comparison, between *A. lebbeck* and *S. siamea, A. lebbeck* had the highest pH value (7.78) at 144 h, while *S. siamea* had the lowest pH value (4.88) at 48 h (Figure 1).

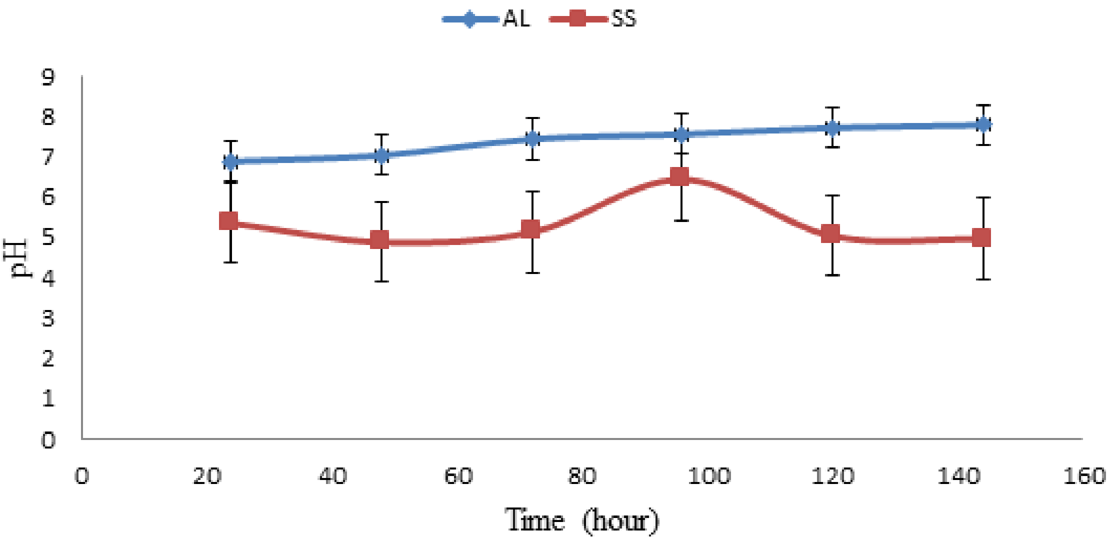

Figure 1: pH in leached water samples of both *A. lebbeck* and *S. siamea* leafy biomass at different time intervals

Dissolved Solids (mg L^{-1})

S. siamea and *A. lebbeck* recorded the highest values (313.66 mL^{-1} and 292.00 mL^{-1}) at 120 h and 144 h, while the lowest values (175.16 mL^{-1} and 162.83 mL^{-1}) were both at 24 h. *S. siamea* had the highest (313.66 mL^{-1}) total dissolved solid at 120 h, while *A. lebbeck* had the lowest value (162.83 mL^{-1}) total dissolved solid at 24 h, respectively (Figure 2).

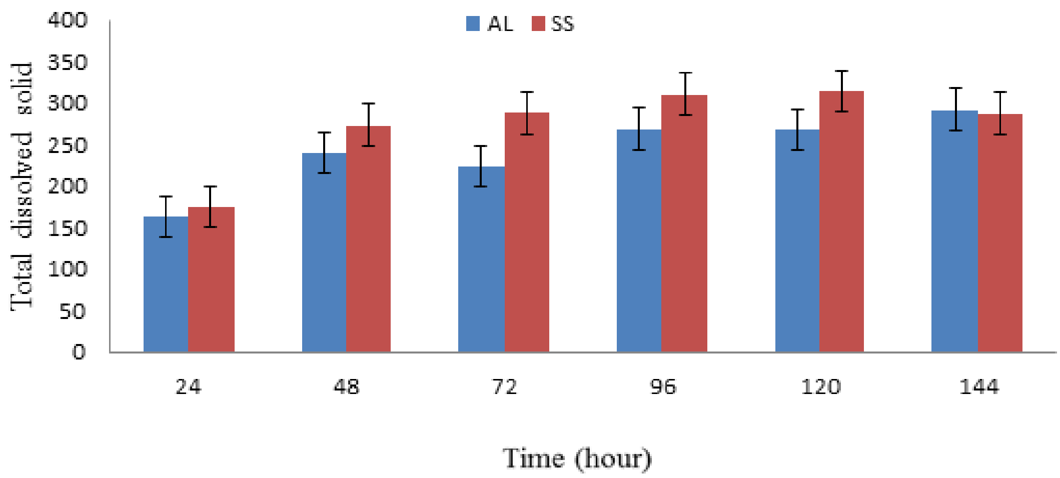

Figure 2: Total dissolved solid in leached water samples of both *A. lebbeck* and *S. siamea* leafy biomass at different time intervals

Suspended Solid (mg L^{-1})

S. siamea and *A. lebbeck* leafy biomass had the highest suspended solid values (313.55 mL^{-1} and 291.96 mL^{-1}) at 120 and 96 h. Meanwhile, the lowest suspended solid values (162.71 mL^{-1} and 156.46 mL^{-1}) were observed in *A. lebbeck* and *S. siamea* at 24 h, respectively. The two leafy biomass leached in a water sample were comparable in that *S. siamea* had the highest and lowest suspended solid values (313.55 mL^{-1} and 156.46 mL^{-1}) at 120 h and 24 h (Figure 3).

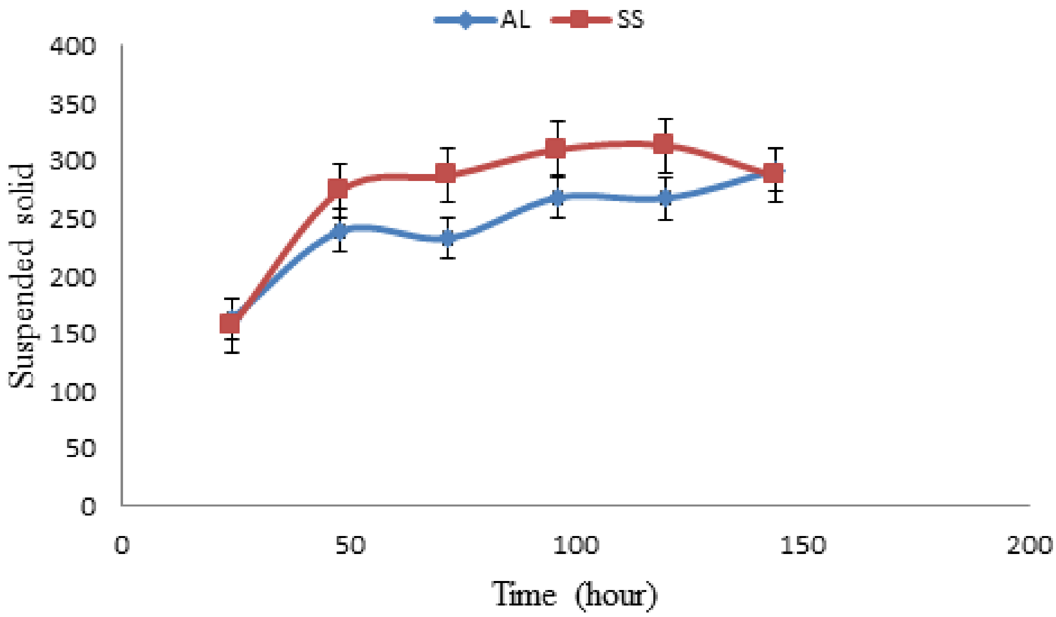

Figure 3: Suspended solid in leached water samples of both *A. lebbeck* and *S. siamea* leafy biomass at different time intervals

Mass Loss (g)

Mass loss values (2.79 g and 2.74 g) of *S. siamea* and *A. lebbeck* leafy biomass were higher at 120 h. However, both *S. siamea* and *A. lebbeck* had the same lowest mass loss value (2.46 g) at 72 h, respectively. In comparison, between the two leafy biomass leached in the water sample, *S. siamea* had the highest mass loss value (2.79 g) at 120 h, while both *S. siamea* and *A. lebbeck* had the same lowest mass loss value (2.46 g) both at 72 h (Figure 4).

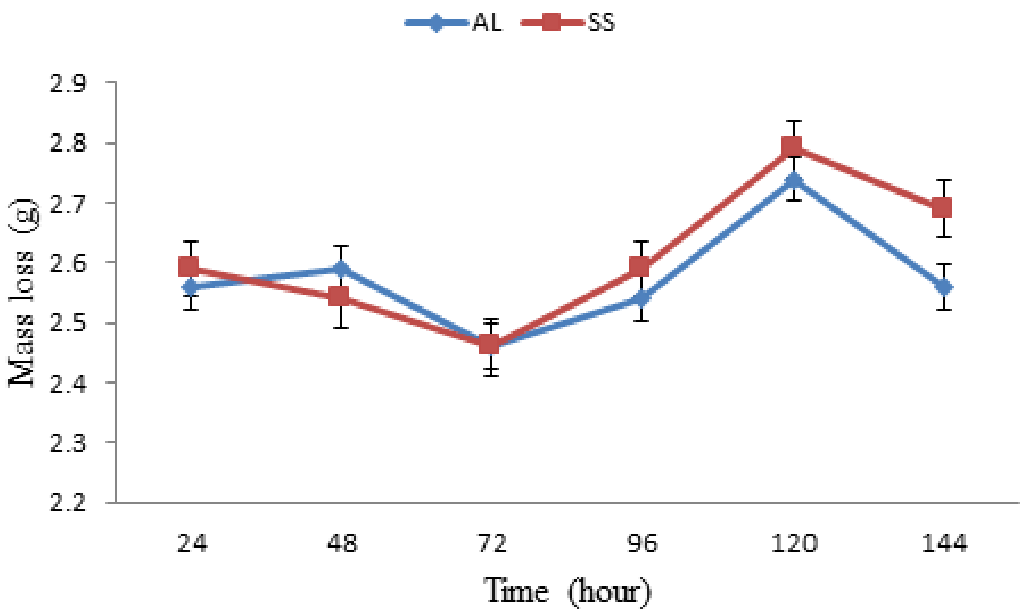

Figure 4: Mass loss in leached water samples of both *A. lebbeck* and *S. siamea* leafy biomass at different time intervals

DISCUSSION

A. lebbeck had higher N and OC, which informed its tendency for rapid decomposition of biomass. Meanwhile, *S. siamea* leafy biomass had lower chemical concentration of C: N, L, L: PP, PP: N, (L+PP): N and cellulose which favours its decomposition. The higher the chemical composition of N and OC and the lower the C: N, L, and PP, the more rapid the decomposition, and the result is in line with Oyebamiji *et al.* (2020). Nitrogen and organic carbon loss in *A. lebbeck* content indicated fast decomposition capacity, which also culminates in the loss of nutrients through leaching.

There was variation in the pH, and it was slightly alkaline after 24 h in water. The variation in the species, whether alkalinity or acidity, revealed more cations concentration in water. However, nutrient loss occurred during the early stage (24 h), this is because gradual decomposition of the plant leafy materials. The result is equally in agreement with the report of Mahmood *et al.* (2009) who stated that nutrients are lost at the early stage of decomposition. The concentration of soluble organic and inorganic substances of the leafy biomass was the reason for differences in nutrient loss, as stated by Hossain *et al.* (2020). Total dissolved solids and suspended solids in both *A. lebbeck* and *S. siamea* experienced an increment in the leaching process.

The significant amount of nitrogen and organic carbon released by *A. lebbeck* leafy biomass indicated that the nutrient content inherent in the leaf could be released faster during decomposition and leaching (Ekow *et al.,* 2016). Phosphorus exhibited no significant difference in both leafy biomasses except in *S. siamea* at 0-24 h. Phosphorus is most readily available and abundant in the meristematic tissue and thus accumulates in the productive parts of the plant. The leaves of both species contained few amounts of phosphorus made available during leaching. The mobile nature of potassium could be the reason for its higher release of nutrients, especially in *S. siamea* at the initial stage of the leaching, i.e., within 24 h. The result is in consonant with Wang *et al.* (2003), who said the rapid release of potassium leads to leaching during the decomposition.

The amount of calcium released from *A. lebbeck* species revealed that it was an immobile element and constituted the structural component of the leafy biomass. This statement alluded to Wang *et al.* (2003) opinion that calcium-released nutrients can result from decomposition and leaching. Leaching also contributed to the release of magnesium and sodium nutrients in the early stage of leaching in both *A. lebbeck* and *S. siamea,* respectively, through microbial activities, which invariably affect the decomposition process of their organic materials. The primary nutrients vulnerable to leaching are nitrogen and potassium because of their weak adsorption capacity (Corley and Tinker, 2003).

CONCLUSION

The result revealed that the average mass loss rate was in both leafy biomass. However, the average nutrient release and loss from the two tree species within the first 72 h. The overall assessment of nutrient release and loss from these two leafy biomass through leaching was comparable, but higher in *S. siamea* than in *A. lebbeck*. Therefore, the recommendation is to select green biomass that are less susceptible to leaching in order to conserve their nutrient potentials. Consequently, the leafy biomass however can still be used as an alternate remedy to improve soil fertility for crop and plant growth and development.

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CONFLICT OF INTEREST

The authors affirm that they have no known financial or interpersonal conflicts that might have appeared to impact the research presented in this paper.

AUTHORS' CONTRIBUTION

Dr. N.A. Oyebamiji conceived the idea and is the principal investigator; Dr. O.M. Bello and Mr. U.A. Isyaku worked on filtration and leaching procedures in the laboratory. O.O. Opanike analyzed the data, and O.O. Ojekunle and U.E. Ekwugha edited the manuscript. All authors read and approved the final manuscript.

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