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Full Length Research Article

Eco-evaluation of the Nutrient Dynamics of Dry Season Litterfall in a Guinea Savanna, North-Central Nigeria

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ABSTRACT

Savannas are prominent members of tropical terrestrial ecosystems. Leaf and branch litter fractions were sampled from ten isolated, natural tree stands of *Azadirachta indica* (A. Juss), *Daniella oliveri* (Rolfe) Hutch & Dalziel, *Parkia biglobosa* (Jacq.) Benth.,*Prosopis africana* (Guill.&Perr.) and *Vitellaria paradoxa* (Gaertner) F.}, in the dry season. Litterfall samples were analysed for Calcium and Magnesium (Atomic Absorption Spectrophotometry) (AAS), Potassium (Flame Photometry), Nitrate-nitrogen and Phosphate-phosphorus (Colorimetric titration). Results showed that branch litter fractions generally returned higher nutrient content than leaf litter. While, the eco-physiologically significant potassium, nitrate-nitrogen, and magnesium were top of the nutrient return spectrum across the litter fractions, with a prominent nutrient return magnitude in the form of K > NO_3-N^- > Mg > Ca > PO_4^{3}-P^-. This indicates the biogeochemical significance of tree litter in tropical savanna ecosystems. Equally, the outcomes of this study indicate the ecological significance of tropical savanna tree cover in litterfall production, decomposition, as well as base content supply and cycling, for soil fertility.

Keywords: Branch litter, dry season, leaf litter, nutrient dynamics, savanna, tree cover.

INTRODUCTION

Savannas are widespread, ever-present tropical and sub-tropical ecotypes, ranging from grasslands, and woodlands, including a heterogeneous mix of both (Bustamante *et al*., 2006). African savannas make up about 50% of global terrestrial ecotypes (Osborne *et al*., 2018). They are characteristically structured by grasses interspersed with trees and shrubs (Konare *et al*., 2021). Trees are ecologically significant in savanna ecosystems in terms of soil fertility management via litter production and decomposition (Anka and Sanda, 2020). Savanna trees also have the ability to modify their environment, thus creating heterogeneous soil characteristics (Konare *et al.,* 2021).

Nutrients are cycled in the ecosystem through fallen plant part fractions in the form of litter, where percolating water enables nutrient leaching and microbial decomposition of litter is a key process (Eaton *et al.,* 1973). Plants acquire over 70% of their nutrients via litterfall (Campos *et al.,* 2017). Litterfall is a major component of soil nutrient dynamics essentially because it is chiefly involved in the formation of soil litter layer. Litter accumulation reduces bulk density and improves the cation exchange and water-holding capacities of soils (Seta *et al.,* 2018). It also lowers the heat amplitude in soils through the mechanism of sunlight interception (Krishna and Mohan, 2017). Tropical trees have been identified with the ability to sustain high levels of soil nutrients, translocating them from deep to top soil layers, thereby creating a surface soil nutrient pool (Gindaba *et al.,* 2005; Hobbie, 2015; Dollinger and Jose, 2018; Suarez *et al.,* 2021). Equally, reports have identified the preferential micronutrient resorption potential for potassium, phosphorus, nitrogen, and sulphur, in tropical trees, as enabling adaptability to environmental variability (Du *et al.,* 2017; Prieto and Querejeta, 2020; Du *et al.,* 2021).

Nutrient fluxes such as litterfall production and decomposition are central processes in the biogeochemical cycle, which tend to reflect the dynamics of production, as well as nutrient balance (Sayer and Tanner, 2010; Nakagawa *et al.,* 2019). In terrestrial ecosystems, litter input and decomposition are essential for biogeochemical cycle reactivation, as well as soil fertility increase (Feng *et al.,* 2019; Giweta *et al.,* 2020). This is not far-fetched as litterfall has been identified as a major nutrient pool in the biogeochemical cycle (Congdon and Lamb, 1990). The above-ground litter represents a major carbon and nutrient transfer link, between the plant component and soil when decomposition occurs (Arunachalam *et al.,* 1998; Pitman *et al*., 2010; Farooq *et al*., 2020; da Silva Rocha *et al.,* 2022). In tropical and semi-arid ecosystems, nutrient recycling via litter decomposition has been identified as a long-standing fertility sustenance factor (Richards, 1996; Sayer and Tanner, 2010; Bankole *et al.,* 2023). Degraded lands due to industrial anthropogenic activities such as mining are characterized by a loss of soil surface plant cover and litter, which disrupts the biogeochemical cycling of nutrients (Osorio, 2012; Leon *et al.,* 2013; Restrepo *et al.,* 2013; Valente *et al.,* 2023). Similarly, trees in agroforestry and plantation systems are typically useful in soil quality improvement via mechanisms such as abundant root exploration systems, and soil surface protection through litter generation and decomposition (Lemenih *et al.,* 2004; Moorhead and Sinsabaugh, 2006; Zingore *et al.,* 2008; Celentano *et al.,* 2011; Murgueitio *et al.,* 2011; Fahad *et al.,* 2022).

As plants develop, leaves are shed, and these leaves and dead branches decay, returning nutrients to the soil for plant utility. Litterfall can be fresh, undecomposed plant debris, ranging from leaves, twigs, needles, cones, barks, seeds or nuts, or reproductive organs (Lonsdale, 1988). According to Spain (1984), the largest amounts of debris fall tend to occur towards the close of the dry season and the onset of the wet season in tropical environments. Litterfall is one of the main fluxes through which nutrients from the main vegetation get to the soil (Herborn and Congdon, 1993).

During leaf senescence, plant nutrient distribution to the leaves occurs, thus accounting for the varied nutrient levels in the litterfall from mature foliage, through the mechanism of reabsorption of constituents (Schlesinger, 1997), and as a result the transfer of nutrients, organic matter, and energy to the soil (Facelli and Pickett, 1991). Vegetation form, growth cycles, withering, and senescence, as well as climatic conditions, influence litter production, which is important for soil aggregate protection against the impacts of raindrops by the inhibition of silt and clay particle percolation in soil pores (Chanasyk *et al.,* 2003; Liu *et al.,* 2004; Cejudo *et al.,* 2022). It also helps in protecting soils from wildfire damage and erosion (nutrient leaching). Dry conditions have been identified with increased leaf litter production as a mechanistic response towards the reduction of evapotranspiration (Sari *et al.,* 2022; Valente *et al.,* 2023).

Azadirachta indica (A. Juss), *Daniella oliveri* (Rolfe) Hutch. & Dalziel, *Parkia biglobosa* (Jacq.) Benth., *Prosopis africana* (Guill.&Perr.), and *Vitellaria oliveri* (Gaertner) F. are tropical savanna tree species commonly found in Africa (Suleiman *et al*., 2018; Soba *et al*., 2023; Somanin *et al*., 2023). They are members of the families Meliaceae (mahogany), Fabaceae, Fabaceae, Fabaceae, and Sapotaceae respectively. The guinea savanna ecosystem typically has sandy, well-drained soils that support the luxuriant growth of the tree species, which in turn possess medicinal, industrial (timber and pulp), nutritional, and economic values, derived from their utility by man and animals (Somanin *et al*., 2023). As a follow-up to soil conservation and fertility replenishment in tropical ecosystems, this study was designed to investigate the nutrient status of the dry season litter flux of dominant tree cover in the savanna study area.

MATERIALS AND METHODS

Study Area

The study was conducted across the dry (November to February) months on the main campus of the University of Ilorin (8.4912°N, 4.5950°E), the Guinea Savanna belt of Nigeria (Oyedeji *et al.,* 2021) (Figure 1). The study area is an undisturbed woodland-grassland characterized by dry (November to March) season months, with 75-80% relative humidity, and an average annual temperature of 33°C-34°C (Ajadi *et al.,* 2011; Oyedeji *et al.,* 2014). The natural vegetation is dominated by grass cover, with significant tree vegetation component chiefly membered by deciduous species like *A. indica, D. oliveri, P. biglobosa*, *P. africana,* and *V. paradoxa*, in sparse distribution patterns (Oyedeji *et al.,* 2014). *Delonix regia*, *Gmelina arborea, Mangifera indica,* and *Terminalia catappa* are also relatively well represented in the study area (Babalola and Raji, 2016; Oyedeji *et al.,* 2021).

Experimental Design, Sample Collection and Preparation

Ten isolated tree stands were sampled in an undisturbed, tree cover-laden savanna study area (two stands per species), for leaf and branch litter fractions. Fallen leaf and branch litter samples were collected weekly, in the four cardinal directions beneath the canopy radius of each tree stand, across the dry November to February months. The collection of samples was selective, on the basis of tree stand isolation factor, to ensure the homogeneity of litter samples to each tree stand.

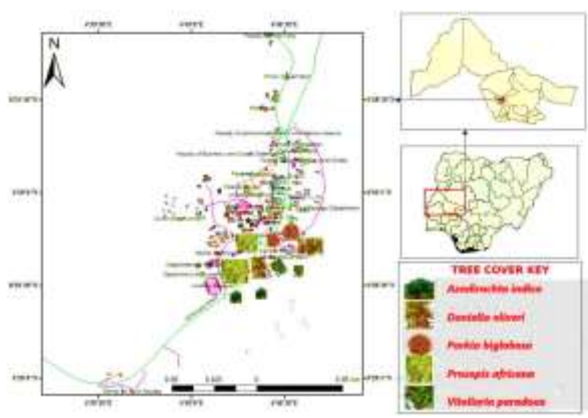

Figure 1: Scale Map of sampling points within the Study Area.

Leaf and branch litter samples were sorted, collected into separate polyethylene nylon bags, air-dried, and stored for laboratory analysis. Air-dried samples were pulverised to powder, after which 1.0 g of each of the litter samples was weighed and analysed for calcium, potassium, magnesium nitrate-nitrogen, and phosphate-phosphorus. Calcium and magnesium were analysed with the Buck Scientific Atomic Absorption Spectrophotometer (Model-210 VPG, Norwalk, United States). Potassium was determined with the JENWAY Flame Photometer, PFP 7 (Illinois, United States). Nitrate-nitrogen and phosphate-phosphorus were determined by the colorimetric titration method, after $HClO_4$-HNO_3 digestion.

Digestion and Laboratory Analysis

Nitric-perchloric acid (HNO_3-$HClO_4$) based digestion was employed (AOAC, 1990). 1.0g each of the pulverized leaf and branch litter samples was weighed into conical flasks. Then, 10mL of conc. trioxonitrate V acid (HNO_3) was added gently, obtaining red-coloured extracts. These extracts were then boiled at 200^{o}C, on an electric hotplate magnetic stirrer (Simmerstat W/PTFE, IEC, Thornbury, Australia) for 20 minutes until a yellowish-white mixture was obtained. The digested solution was then dissolved in 0.1M hydrochloric acid (HCl) and filtered with a Whatman Filter Paper (No 42; 125 mm). A clear solution (digestate) was obtained and collected into 60 mL bottles for chemical analysis.

Statistical Analysis

Data were subjected to a one-way analysis of variance using Fischer's Least Significant Difference method with MINITAB statistical software. Experimental analysis was done in triplicates and statistical differences were measured at 95% confidence.

RESULTS

Table 1 shows that branch litter contained higher calcium content than leaf litter in four of the five tree species (*A. indica*, *D. oliveri*, *P. africana,* and *V. paradoxa*). Potassium concentration was higher in the leaf litter than the branch litter in three of the five tree species (*A. indica*, *P. africana* and *V. paradoxa*) (Table 1). Branch litter contained higher magnesium content than the leaf litter in three of the five tree species (*A. indica*, *P. biglobosa, P. africana*) (Table 1), while there was higher nitrate-nitrogen content in the branch litter than the leaf litter in four of the five tree species (*D. oliveri*, *P. biglobosa*, *P. africana,* and *V. paradoxa*) (Table 1). Phosphate-phosphorus content however, was higher in the leaf litter than in branch litter in four of the five tree species (*A. indica*, *D. oliveri*, *P. africana,* and *V. paradoxa*) (Table 1). Furthermore, the nutrient return trend patterns showed that branch litter was generally higher in nutrient content than leaf litter, for the five tree species.

Table 2 shows the consistency of potassium as the nutrient with the highest magnitude, in the leaf and branch litter of *A. indica*, *D. oliveri*, *P. biglobosa, P. africana* and *V. paradoxa*. The average signature nutrient order in the study area was K > NO_3-N^- > Mg > Ca > PO_4^{3}-P^-. This is deduced from the observations in the leaf litter, where the nutrient order (K > NO_3-N^- > Mg > Ca > PO_4^{3}-P^-) was 60% prominent, as reflected in *A. indica*, *P. africana,* and *V. paradoxa* (Table 2). This same 60% prominence pattern was also identified in the branch litter, of *A. indica*, *P. biglobosa,* and *V. paradoxa* (Table 2). Conversely, but slightly dissimilarly, a second most prominent nutrient order (K > NO_3-N^- > Ca > Mg > PO_4^{3}-P^-) was observed in 40% of the branch litters, which were from *D. oliveri* and *P. africana* (Table 2).

Table 1: Nutrient content (mg/kg) in the leaf and branch litter samples of *A. indica*, *D. oliveri*, *P. biglobosa, P. africana* and *V. paradoxa*

TREE SPECIES	LITTER SAMPLES	CALCIUM	POTASSIUM	MAGNESIUM	NITRATE-NITROGEN	PHOSPHATE-PHOSPHORUS
A. indica	Leaf	2.34 ± 0.65 ^{ab}	120.46 ± 14.18^{a}	2.65 ± 0.68^{a}	5.28 ± 0.07^{ab}	0.05 ± 0.01^{b}
	Branch	2.74 ± 0.45 ^{ab}	52.23 ± 1.04^{bc}	3.07 ± 0.68^{a}	3.81 ± 0.04^{ab}	0.06 ± 0.004^{b}
D. oliveri	Leaf	2.72 ± 0.38 ^{ab}	33.86 ± 10.67^{c}	3.08 ± 1.03^{a}	2.67 ± 0.73^{b}	0.05 ± 0.02^{b}
	Branch	3.06 ± 0.20 ^{a}	43.16 ± 12.27^{c}	2.84 ± 0.32^{a}	5.32 ± 0.66^{ab}	0.07 ± 0.01^{b}
P. biglobosa	Leaf	2.16 ± 0.16^{bc}	54.36 ± 0.35^{bc}	1.69 ± 0.42^{a}	4.84 ± 1.38^{ab}	2.03 ± 2.43^{a}
	Branch	2.13 ± 0.22^{bc}	71.78 ± 17.48^{b}	2.47 ± 0.57^{a}	5.45 ± 0.78^{a}	0.08 ± 0.01^{b}
P. africana	Leaf	1.28 ±0.52^{cd}	38.01 ± 23.47^{c}	1.63 ± 1.15^{a}	3.50 ± 2.48^{ab}	0.04 ± 0.03^{b}
	Branch	2.15 ± 0.25^{bc}	34.38 ± 1.78^{c}	1.82 ± 0.58^{a}	3.69 ± 1.44^{ab}	0.05 ± 0.02^{b}
V. paradoxa	Leaf	1.06 ± 0.34^{d}	60.46 ± 2.16^{bc}	2.53 ± 0.32^{a}	2.55 ± 0.37^{b}	0.04 ± 0.004^{b}
	Branch	2.31 ± 0.05 ^{ab}	38.03 ± 3.23^{c}	2.46 ± 0.32^{a}	4.97 ± 1.19^{ab}	0.06 ± 0.01^{b}

Table 2: Nutrient return magnitude of the litterflux of *A. indica*, *D. oliveri*, *P. biglobosa, P. africana* and *V. paradoxa*

TREE SPECIES	LITTERFLUX	NUTRIENT RETURN ORDER
A. indica	Leaf	K > NO_3-N^- > Mg > Ca > PO_4^{3}-P^-
	Branch	K > NO_3-N^- > Mg > Ca > PO_4^{3}-P^-
D. oliveri	Leaf	K > Mg > Ca > NO_3-N^- > PO_4^{3}-P^-
	Branch	K > NO_3-N^- > Ca > Mg> PO_4^{3}-P^-
P. biglobosa	Leaf	K > NO_3-N^- > Ca > PO_4^{3}-P^- > Mg
	Branch	K > NO_3-N^- > Mg > Ca > PO_4^{3}-P^-
P. africana	Leaf	K > NO_3-N^- > Mg > Ca > PO_4^{3}-P^-
	Branch	K > NO_3-N^- > Ca > Mg > PO_4^{3}-P^-
V. paradoxa	Leaf	K > NO_3-N^- > Mg > Ca > PO_4^{3}-P^-
	Branch	K > NO_3-N^- > Mg > Ca > PO_4^{3}-P^-

DISCUSSION

Biogeochemical cycle reactivation has been identified as an approach to improving degraded soils and their productivity through the production and decomposition of litter (Leon and Osorio, 2014). The role of trees in the improvement of litter supply, soil quality, nutrient cycling, and water infiltration is also typified in functional mechanisms such as soil exploration by robust root systems and soil surface protection against erosion (Arevalo *et al.*, 2008; Kumar, 2008; Montagnini, 2008; Zingore *et al.*, 2008). Long-term interactions and affinity between prominent tree species and the soil in their microenvironment have also been implicated in the development of suitable conditions for their litter decomposability (Anka and Sanda, 2020). Cationic elements such as calcium, potassium, and magnesium are essential for plant mechanisms such as photosynthetic activity, stress resistance, and structural development (Karley and White, 2009; Hasanuzzaman *et al*., 2018; Trankner and Jamali Jaghdani, 2019). Phosphorus and potassium have been identified as central to the primary productivity of terrestrial ecosystems, due to their relatively intensive cyclability by plants (Jobbagy and Jackson, 2001; Knecht and Goransson, 2004). Nitrogen and phosphorus are members of the most important terrestrial ecosystem nutrients derived from dead plant matter, that have key functionality in plant growth, ecosystem production, and structure (Huntley, 2023). They serve as ecological filters in terrestrial ecosystems through the regulation of savanna biome establishment (Pellegrini, 2016; Almeida *et al*., 2018).

The nutrient return order from the findings in this study reflected a 60% dominant nutrient returns pattern in the form of (K > NO_3-N^-> Mg > Ca > PO_4^{3}-P^-) in *A. indica* and *V. paradoxa*, *D. oliveri* (branch litter), *P. biglobosa* (branch litter) and *P. africana* (leaf litter). Potassium was the most returned of all the nutrients across the board. The high potassium levels detected across the tree species in the study site could be indicative of the dry conditions associated with rainfall shortage which prevents the leaching of potassium from litterfall (Egunjobi, 1971; Egunjobi and Fasehun, 1972; Saha *et al.*, 2016). Potassium is equally an essential nutrient taken up by plants in higher quantities than virtually most nutrient elements making them central to tropical vegetation functioning (Roy *et al.*, 2005; Lloyd *et al.*, 2015). Furthermore, terrestrial ecosystems have been reported to have a huge potassium retention capacity, which has been identified as a significant evolutionary mechanism for ensuring potassium availability (Sardans and Peneulas, 2021).

Nitrate-nitrogen was consistently the second most returned litterfall nutrient in the study area. This is explainable on the basis that nitrate-nitrogen enrichment beneath tree canopies has been reported as a factor of the nitrification stimulation role of trees, as well as, tree preference for nitrate-nitrogen, as evidenced in the Lamto Savanna tree species *Hyparrhenia diplandra* (Konare *et al.*, 2021). Robertson and Vitousek (2009) also identified nitrates as one of the most mobile nitrogenic forms in soils and absorbed by plants. Calcium and magnesium also featured prominently and are eco-physiologically significant in the sense that they are implicated in soil fertility, base content, and light-dependent and independent photosynthetic phases (van der Heijden *et al.*, 2014; Trankner *et al.*, 2018).

CONCLUSION

This study highlights the significance of leaf and branch litter fractions as dominant components of tree cover litter flux, in tropical savanna floor ecosystems. The major nutrient returns of cationic elements such as potassium, magnesium calcium, and the anionic nitrate-nitrogen in this study, possess eco-physiological relevance in terms of vegetation and soil functionality. Thus, indicator savanna tree species will become even more central in achieving sustainable ecosystem functionality such as nutrient cycling, soil fertility, and mulching driven-conservation. Furthermore, tropical savanna trees are also suitably essential for agroforestry, and mitigatory roles against ecological challenges such as desertification encroachment, as well as drivers of the great green wall initiative across the tropical, sub-Saharan region.

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