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LITTER DIVERSITY IMPROVES LITTER FALL AND NUTRIENTS SUSTAINABILITY IN AN AGROFORESTRY SYSTEM IN A SEMI-ARID ECOSYSTEM IN JUJA, KENYA

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ABSTRACT

Trees in agroforestry are important for the cycling and sustainability of nutrients; however, documentation on the decomposition and nutrient release as influenced by tree diversity is scarce in agroforestry. This study aimed to determine the effect of litter diversity of five commonly used agroforestry tree species (Cordia Africana (Lam.), Faidherbia albida (Del.), Grevillea robusta (A.Cunn.), Acacia seyal (Del.), and Acacia xanthophloea (Benth.) on nutrient release in an agroforestry ecosystem in Juja, Kenya. Litter bag techniques were adopted to determine the quantity and quality of nutrients released in the mixed litters of the five tree species compared with the individual species. The mineralization of N, P, K, and C significantly increased in A. seyal among individual tree litters, hence, proves its suitability for agroforestry. However, tree diversity increased litter fall by 82% and 33% compared with those of F. albida and A. xanthophloea, respectively. Potassium and C released in the mixed litter were not significantly different from their corresponding monocultures. Meanwhile, an antagonistic non-additive effect of mixed litter was observed on N and P after 90 days of decomposition, thereby ensuring their retention and sustenance in agroforestry system.

Key words: Agroforestry; Nutrients sustainability; Species richness; Additive effect; Non-additive effect

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INTRODUCTION

The diversity of plant species has a significant impact on the functioning of ecosystems (Corlett 2016). The litter from trees, crops, and other plants is typically mixed and decomposed together in the soil (Zeng *et al*. 2010). However, the quality and quantity of residues produced by each plant species differ and in turn affects the rate of decomposition and nutrient release.

The decomposition and nutrient release pattern cannot be attributed to a single factor (Prescott 2005, Waring 2012), but depends on both biotic and abiotic factors, including litter composition, moisture, temperature, and microbial activities (Schwarz *et al*. 2015). In an agroecosystem, the decomposition and nutrient release pattern from litter could be non-additive; that is, there is a difference between the observed effect in the mixed litter and the expected effect of monoculture. Non-additive can either be synergistic non-additive (observed effect higher than the expected) or antagonistic non-additive (observed effect less than the expected) (Dijkstra *et al*. 2009, Li *et al*. 2020). There is also evidence of an additive effect on litter decomposition and nutrient release, indicating no significant difference between the observed and the expected effects on litter (Li *et al*. 2020). The expected value is the average litter decomposition and nutrient release of the monoculture, while the observed value is the corresponding parameter of the species mixture.

The synergistic non-additive effects of mixed litter could be caused by nutrient transfer (Gartner and Cardon 2004) or an improved environment for microbial activities (Otsing *et al*. 2018, Purahong *et al*. 2014). The antagonistic non-additive effects could be caused by the presence of lignin and cellulose, increasing the toughness of litters for microbial breakdown (Jacobs *et al*. 2018, Mao *et al*. 2017). Cornwell *et al*. (2008) also reported that high nitrogen (N) content could bring about a high nitrogen to phosphorus ratio beyond the optimal level for decomposition, resulting in an antagonistic non-additive effect. However, the additive effect in litter mixtures could be caused by the interaction or transfer of nutrients among species in the mixture (Guerrero-Ramirez *et al*. 2016, Hoorens *et al*. 2010).

Litter chemistry plays an important role in determining the rate of litter decomposition (Mao *et al*. 2017, Zhang *et al*. 2008). The amount of nutrients released in a particular area depends on the quality of the litter fall. Previous researches on litter decomposition and nutrient release have primarily concentrated on natural ecosystems. These include tropical forests (Hättenschwiler and Jørgensen 2010), temperate forests (Ball *et al*. 2008, Gao *et al*. 2015), subalpine forests (Bisht *et al*. 2014), mangrove forests (Fernando and Bandeira 2009), terrestrial ecosystems (Hattenschwiler *et al*. 2005), peatlands (Hoorens *et al*., 2009), but limited attention has been given to agroforestry systems, especially in the semi-arid parts of Kenya.

Litter falls and their productivity are two of the most important factors that influence nutrient cycling in an agroecosystem (Fernando and Bandeira 2009). The faster the litter nutrients are released, the more fertile and productive the soil becomes (Jacobs *et al*. 2018). The combination of tree species on a farm results in the combination of their corresponding litters. However, it remains unknown if a priming effect exists among the different tree species with high nutrient concentration and those with low nutrient concentration (Liu *et al*. 2007, Schwarz *et al*. 2015). Predicting ecosystem nutrient dynamics in mixed species plots like agroforestry systems might be inaccurate if nutrients released are observed based on the contribution of each component species (Ball *et al*. 2008). Therefore, it is important to understand how species interact and how their interactions affect nutrient dynamics in an agroecosystem.

Immobilization of nutrients from the environment may occur as a result of insufficient nutrients required for decomposition in plant litter as soil microbes require an adequate amount of N or P from the litter to consume C for energy release (Li *et al*. 2020). This could result in a decrease in the nutrient content of the soil during decomposition (Chen *et al*. 2015). Therefore, information on suitable tree combinations is required for the improvement of nutrient cycling that can improve soil quality in agroforestry. Hence, quantifying litter falls and litter productivity is vital to determining their specific and collective contribution to nutrient release in a semi-arid agroecosystem. The objectives of the study were to determine (a) the quantity of litter fall of individual tree species and their respective contributions to nutrients released and (b) if litter mixture can promote nutrients released in an agroforestry ecosystem during decomposition.

MATERIALS AND METHODS

Study Area

The field experiment was carried out during the bimodal seasons (April to September, 2016) at an agroforestry experimental site in Juja, Kenya (latitude 0°10′48″S, longitude 37°7′12″E). The average annual temperature and rainfall of this region was 18.8°C and 1014 mm, respectively (Baloïtcha *et al*. 2022). The soil of the experimental field is characterized as chromic vertisols with a pH of 5.8 at 0 –15 cm depth.

Experimental design and sample collection

The quantity of litter fall, processes of decomposition and mineralization determine an ecosystem's productivity (Fernando and Bandeira 2009). Five commonly used agroforestry tree species in Kenya [*Cordia Africana* (Lam.), *Faidherbia albida* (Del.), *Grevillea robusta* (A.Cunn.), *Acacia seyal* (Del.), and *Acacia xanthophloea* (Benth.)] were involved in this study for the period of six months. This experimental period included three months at the end of the rainy season

(April - June) and three months at the beginning of the dry season (July - September) to capture the variation in the litter fall habit of the tree species. The description of the tree species including their common name, Latin name, family, and habit are presented in Table 1. The experimental site with a total area of 35,500m^2 was previously used as a grazing land before trees were established in 2011. For this study, a plot size of 50m × 40m consisting of seven rows of the mixed tree species was mapped out. The trees were randomly planted at an equidistance of 5 m for both inter and intra row spacing. Each row consists of at least nine tree stands with a representative of each species. Notably, the inter-row spacing was used for maize (*Zea mays*) cultivation during the rainy season.

Table 1: Description of studied tree species based on their family name, common name, and litter-fall habit.

Species	Family name	Common name	Litter-fall habit
Cordia Africana	Boraginaceae	Sudan teak / Wanza	Deciduous
Faidherbia albida	Fabaceae	Ana tree / Mogabo	Inverse phenology
Grevillea robusta	Proteaceae	Silk oak / Mukima	Evergreen
Acacia seyal	Mimosoideae	Shittim wood / mgunga	Evergreen
Acacia xanthophloea	Fabaceae	Fever tree / Murera	Evergreen

Three conical litter traps were used to quantify the total litter fall of each tree species. Each conical litter trap with a diameter of 31.8 cm and an area of 794.33 cm^2 was positioned 30 cm above ground level and 50 cm from the base of the randomly selected trees. The litters were collected from the conical litter traps at 15 days' interval for 6 months. The litter fall by each species in grams per square centimeter (g cm^{-2}) to the area of the conical litter trap was used to estimate litter fall by each species in kg per hectare (kg ha^{-1}) for the six month. Meanwhile, the average of the combined litters of the five species was considered as the mixed litter fall.

For the decomposition study, matured fallen leaves of each species were collected at the base of the trees in different bags and were oven-dried at 65°C to a constant weight. The oven-dried litters were crushed to small sizes (1-3 cm). A total of 120 litter bags were used for the decomposition study. Each litter bag (20×13 cm) made with a mesh size of 1 mm was filled with 25 g of crushed litters of the five species and their composite (six treatments). Notably, 5 g of the litter of each species were mixed to form the 25 g of the composite litter.

Twenty-four litter bags (six treatments and four replicates) were retained for initial nutrient content analysis, while the remaining 96 litter bags (6 treatments, 4 replicates, and 4 sampling dates) were positioned on the experimental plots for decomposition study.

Data collection

Samples were collected from the litter bags after 15, 30, 56, and 90 days of decomposition on the field. Collected samples were oven dried at 65°C until a constant weight and were analyzed for N, P, K, and C. The total organic carbon was determined by chromic digestion and spectrophotometry; total nitrogen by microscopic Kjeldahl digestion followed by distillation. Using the same digestion solution as for nitrogen, phosphorus was measured by colorimetry with an UV mini 1240 spectrophotometer, while potassium was measured with a flame photometer (FP-501).

The nutrient mass at each sampling period was calculated by multiplying the nutrient content (mg/g) of the litter by the dry mass at the sampling time (Ball *et al*. 2008). The amount of nutrients released at each sampling time was determined by subtracting the amount of nutrients remaining in the litter at each sampling time from the amount of initial nutrients present.

The average nutrient mass loss in each monoculture was compared with the corresponding mixture of the monocultures to determine the composite effect (either additive or non-additive) on mineralized nutrients

(Gartner and Cardon 2004). If non-additive was observed, the strength of interaction was calculated using the formula below.

$$\text{Interraction strength} = 1 - \left(\frac{\text{Expected}}{\text{Observed}}\right) \quad \text{…. [1]}$$

A positive interaction occurs when the observed nutrient released exceeds the expected nutrient released which signifies a synergistic non-additive effect, while a negative interaction occurs when the expected nutrient released exceeds the observed indicating an antagonistic non-additive effect. The strength was measured based on the resultant deviation from zero. The average nutrient mass loss in all compositions was used to determine the nutrient that had a significant effect on the nutrient dynamics in each composition.

Data analysis

Statistical analysis was done using IBM SPSS version 21. An independent sample t-test was used to compare the nutrient released between the expected and observed. However, the differences in litter fall among species, and nutrient loss were determined using one-way analysis of variance (ANOVA) at $\alpha = 0.05$.

RESULTS

The litter falls collected from the five tree species and their estimated composite did not differ significantly. However, *A. seyal* had the highest litter fall, with 28% of the total litter fall, while the lowest litter fall was recorded in *F. albida*. Compared to *F. albida* and *A. xanthophloea*, the mixed litter fall increased by 82% and 33%, respectively. However, it decreased by 4%, 25%, and 30%, respectively, compared to *C. africana*, *G. robusta*, and *A. seyal* (Figure 1).

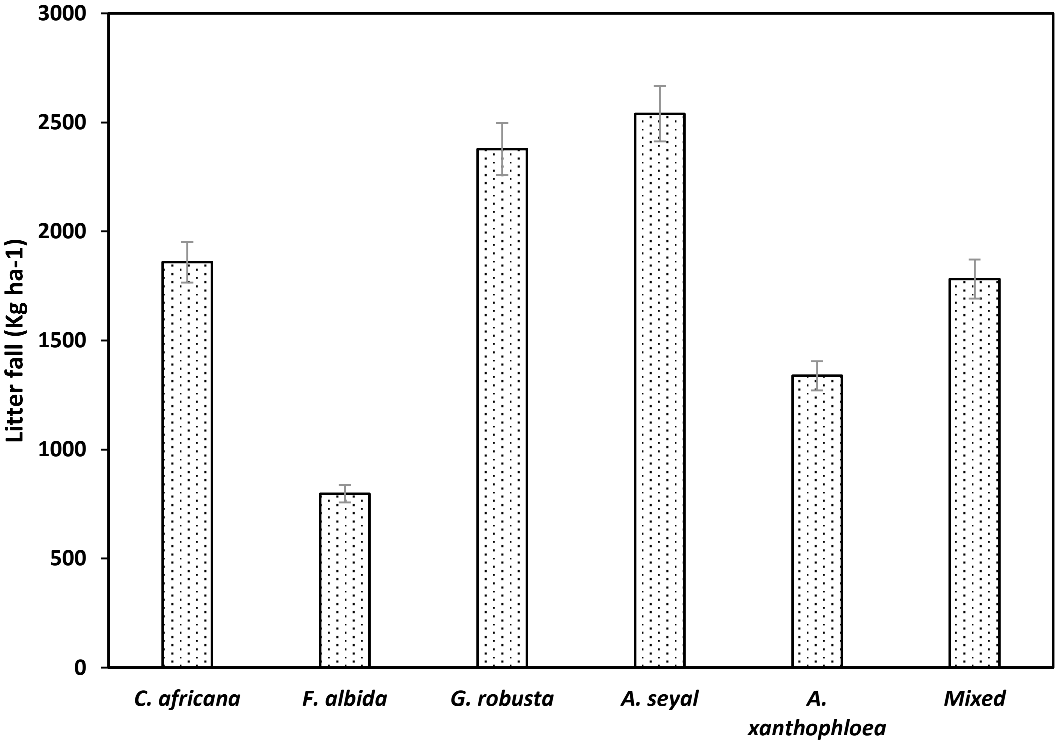

Figure 1: Litter fall (kg ha^{-1}) of agroforestry tree species and the average of their combinations (mixed) after six months of collection.

F. albida had the highest initial nitrogen (N) mass concentration and it mineralized the highest amount of N after 90 days of decomposition (Table 2 and 3). Individual tree species with higher initial N mass concentration (*F. albida* and *A. seyal*) mineralized more N after 90 days, but N was immobilized in the mixed and *C. africana* (Table 3). *A. seyal* released the highest total amount of phosphorus (P), potassium (K), and carbon (C) to the ecosystem after six months of decomposition (Table 3). Among the treatments, N and P released were significant ($p<0.05$) after 90 days of decomposition, whereas K and C released were not significantly different (Table 3).

Table 2. Initial nutrient mass present in leaves of agroforestry tree species.

Species	Initial nutrient mass (mg/g)					
	N	**P**	**K**	**C**	**C:N**	**N:P**
C. africana	4.56	0.58	0.90	79.13	25.32	7.86
F. albida	10.14	0.41	0.34	54.91	5.80	24.73
G. robusta	4.21	0.45	0.44	70.42	17.20	9.36
A.seyal	9.30	0.38	0.33	51.12	12.79	24.47
A.xanthophloea	7.12	0.46	0.34	57.97	8.58	15.48
Mixed	5.69	0.37	0.63	64.27	13.67	15.38

The initial N contents of the mixed litter were higher than those of *C. africana* and *G. robusta*, respectively. However, N was mineralized in *G. robusta* after 90 days while immobilization of N was observed in the mixed litter composition and *C. africana*, as indicated by their negative values (-0.74 and -0.61 respectively) (Table 3). The N, P, and C released differed among the treatments, but the C released was not significantly different (Table 3).

Table 3: **Mass of nutrient mineralized or immobilized in agroforestry tree litter after 90 days of decomposition.**

Species	Nutrient mineralized or immobilized after 90 days decomposition (mg/g)			
	N	**P**	**K**	**C**
C. africana	-0.61^{c}	0.27^{ab}	0.65^{a}	20.62^{ab}
F. albida	8.85^{a}	0.34^{ab}	0.81^{a}	25.84^{ab}
G. robusta	1.19^{bc}	0.10^{bc}	0.81^{a}	15.08^{ab}
A.seyal	7.34^{ab}	0.47^{a}	0.92^{a}	34.38^{a}
A.xanthophloea	3.33^{ab}	0.39^{a}	0.66^{a}	8.53^{b}
Mixed	-0.74^{c}	0.03^{c}	1.12^{a}	21.95^{ab}
	*	*	ns	ns

*Values within a column followed by different superscript letters are significantly different. * means significant difference at p<0.05 by Duncan's multiple range test, while ns indicates non- significant difference*

There were variations in the percentage of nutrients released across the 90 days of decomposition, as shown in Figure 2. Nitrogen was immobilized in *C. africana* in the first 15 days but had the highest percentage of N released on the 90th day of decomposition, while the combination of the five tree species had the lowest N released on the 90th day. The N released from *C. africana* on the 90th day of decomposition was 199% higher when compared with that of the mixed (Figure 2A). The percentage of P released was highest in *A. xanthophloea* and lowest in the mix. The P released in the mix was reduced by 111% compared with the P released by *A. xanthophloea* (Figure 2B). The amount of K released was highest in *A. seyal* and lowest in *C. africana*. *A. seyal* increase K released by 25% compared with that of *C. africana* (Figure 2C). Figure 2D shows that *A. xanthophloea* released the highest C on the 90th day, although C was immobilized in the first 15 days; however, *C. africana* released the lowest C on the 90th day. The C released by *A. xanthophloea* was 124% higher than the C released by *C. Africana*. The percentage of K and C released in the mix was higher than that of *C. africana* by 86% and 32%, respectively, and *G. robusta* by 86% and 42%, respectively, but immobilization of N and P occurred on the 90th day of decomposition (Figure 2).

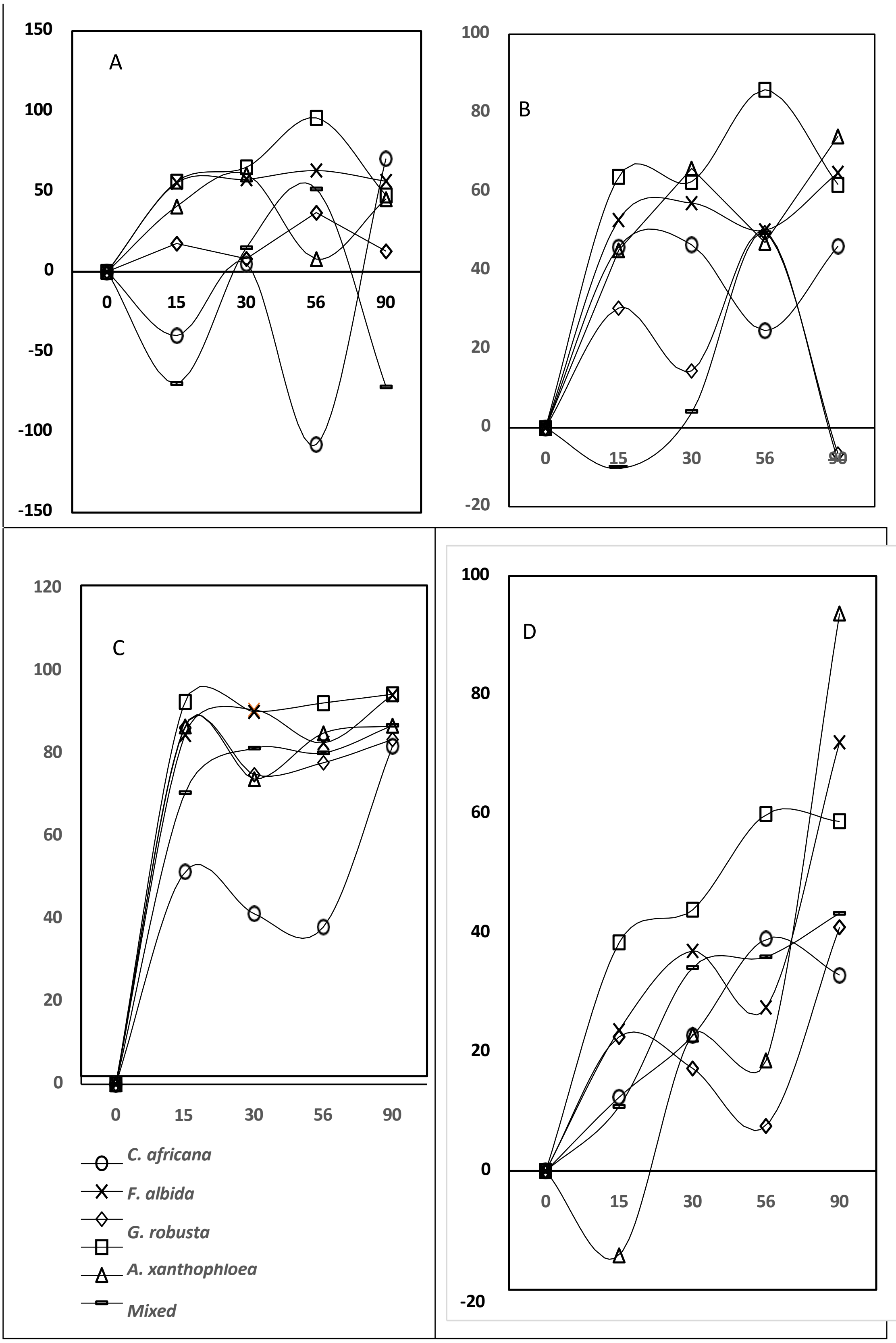

Figure 2: Nutrient released from litter after 15, 30, 56, and 90 days of decomposition. A represent nitrogen released, B Phosphorus released, C Potassium released, and D Carbon released. Y axis shows the percentages of the nutrient released or immobilized while X axis is the time represented in days.

There were no significant differences between the expected and observed values of K and C released, thereby indicating an additive effect. The K and C observed were 43% and 2% higher than the value of the expected. However, there was a significant difference at $p \leq 0.05$ between the observed and expected nutrient released for N and P thereby indicating a non-additive effect (Table 4). The N and P observed were 118% and 90% lower than the expected.

Table 4: The strength of interaction between observed and expected values of some released nutrients in agroforestry tree litters after 90 days of decomposition

Nutrients	Observed (mg/g)	Expected (mg/g)	p value	Interaction strength
N	-0.92	5.03	0.02	-4.47
P	0.04	0.39	0.05	-8.75
K	1.39	0.97	0.89	0.3
C	26.54	26.11	0.74	0.02

Values of observed and expected values of each nutrient were significantly different at $p \leq 0.05$ using independent sample t–test.

The non-additive effect was further explored to determine if they were synergistic or antagonistic. Potassium and carbon had a positive strength of interaction between the expected and observed nutrient released with strength values of 0.3 and 0.02 respectively, indicating a synergistic effect. However, N and P showed a negative strength of interaction between the expected and observed nutrients released, with a strength value of -4.47 and -8.75, respectively, indicating an antagonistic effect (Table 4).

DISCUSSION

Bisht *et al*. (2014) reported that nutrients released could be associated with the rate of litter fall. In this study, the comparable quantity of litter collected from the five tree species could be attributed to the pattern of litter shedding and the duration of collection. *C. africana*, a deciduous tree, shed the majority of its leaves in the dry season and re-flushes during the rainy season (Wolfe *et al*. 2016). However, *G. robusta* and *A. xanthophloea* are evergreen trees, and their rate of litter fall is consistent throughout the year. *F. albida,* on the other hand, has inverse phenology and loses its leaves when the rainy season begins (Stephen *et al*. 2020).

We presumed in this study that the period of litter fall collection (end of raining and beginning of dry seasons) accommodated the variation in the leaf shedding pattern of all the tree species, thereby accounted for the comparable quantities of litter fall across the tree species. The increase in average litter fall of the five tree species indicates that the mixed planting of trees could help increase litter fall in the agroforestry system more than the monoculture of *F. albida* and *A. xanthophloea* as shown in Figure 1.

The significant increase in N, P, K, and C mineralized in *A. seyal* litter proves its suitability for agroforestry among tree species observed. The initial nutrient mass in each tree species corresponds to the mass of nutrients released. However, the mixed litter released less N compared with its initial N mass. This observation shows that the initial nutrient concentration could be used as an indicator to determine nutrients released in monoculture during decomposition but not applicable to mixed litter decomposition. This shows that the rate of nutrient release in mixed compositions was regulated by individual species rather than species richness (Hoorens *et al*. 2009, Jacob *et al*. 2010).

The immobilization of N and slow mineralization of P in the mixed litters of the five tree species could be attributed to the mixed litter's low initial P content. Low P in litter could bring about high N/P, which could reduce decomposition in litter (Cornwell *et al*. 2008). The immobilization of N in this study has also been reported in a previous finding by Zhang *et al*. (2020), that the reduced quality of individual litters will cause immobilization of nutrients in mixed composition. The low quality litter in species mixture can also promote nutrient retention in an ecosystem, providing nutrient resources for future decay processes and long-term nutrient storage in litter layers (Ball *et al*. 2008). As a result, immobilization of N in the species mixture after 90 days of decomposition could promote nutrient retention in the ecosystem and promote availability of the nutrients for future use.

Potassium and carbon released by the mixed litter were not significantly different from the average of their corresponding monocultures, indicating an additive effect. The additive effect observed could be associated with the balancing effect during decomposition and nutrient release between litters that induced negative effects and those that induced positive effects, thereby resulting in no significant difference between observed and expected values (Li *et al*. 2020). The antagonistic non-additive effect of N and P as denoted by their negative strength of interaction between the observed and expected nutrients mineralized is in line with the study of Chen *et al*. (2015) that reported an antagonistic non-additive effect of mixed litter on CH_4 uptake in an alpine steppe soil in Northern Tibet. The antagonistic non-additive effect in this study could probably be due to the increase in the level of lignin and cellulose in the mixed litter that possibly slows down the ability of microbes to degrade N in the composition (Jacobs *et al*. 2018, Mao *et al*. 2017).

The changes observed in the mineralization of mixed and monoculture litters were determined by their differences in N and P released, hence indicating their active roles during litter decomposition. N and P are the nutrients-limiting elements that determine the quality of tree species (Agren *et al*. 2012, Knecht, Göransson 2004); hence, they control how nutrients are released into the ecosystem.

CONCLUSIONS

In comparison with tree monocultures such as *F. albida* and *A. xanthophloea*, tree diversity increased litter fall and improved nutrient sustainability in an agroforestry system. However, the rate of nutrient release was based on individual species rather than species richness. Therefore, the selection of individual tree species with quality litter composition is necessary to ensure richness and nutrient availability in agroforestry. *A. seyal* is recommended for fast nutrient release, while the mixture of selected tree species will be appropriate for gradual nutrient release and sustainability of nutrients in an agroforestry system. Mixed litter had an antagonistic non-additive effect on N and P after 90 days of decomposition, thereby ensuring their retention and sustenance in the agroecosystem.

REFERENCES

Agren, G.I. Wetterstedt, J.Å. and Billberger M.F. (2012). Nutrient limitation on terrestrial plant growth - modeling the interaction between nitrogen and phosphorus. *New Phytologist*, 194(4): 953–960.

Ball, B.A. Bradford, M.A. Hunter, M.D. Ball, B.A. Bradford, M.A. and Hunter, M.D. (2008). Nitrogen and Phosphorus Release from mixed litter layers is lower than predicted from single species decay. *Ecosystems*, 12(1): 87–100.

Baloïtcha, G.M.P. Mayabi, A.O. and Home, P.G. (2022). Evaluation of water quality and potential scaling of corrosion in the water supply using water quality and stability indices: A case study of Juja water distribution network, Kenya. *Heliyon*, 8(3): 1–7.

Bisht, V.K. Nautiyal, B.P. Kuniyal, C.P. Prasad, P. and Sundriyal R.C. (2014). Litter Production, Decomposition, and Nutrient Release in Subalpine Forest Communities of the Northwest Himalaya. *Journal of Ecosystems*, 2014: 1–13.

Chen, Y. Sun, J. Xie, F. Yan, Y. Wang, X. Cheng, G. and Lu X. (2015). Non-additive effects of litter diversity on greenhouse gas emissions from alpine steppe soil in Northern Tibet. *Scientific Reports*, 5: 1–11.

Corlett, R.T. (2016). Plant diversity in a changing world: Status, trends, and conservation needs. *Plant Diversity*, 38(1): 10–16.

Cornwell, W.K. Cornelissen, J.H.C. Amatangelo, K. Dorrepaal, E. Eviner, V.T. Godoy, O. Hobbie, S.E. Hoorens, B. Kurokawa, H. Pérez-Harguindeguy, N. Quested, H.M. Santiago, L.S. Wardle, D.A. Wright, I.J. Aerts, R. Allison, S.D. Van Bodegom, P. Brovkin, V. Chatain, A…. and

Westoby, M. (2008). Plant species traits are the predominant control on litter decomposition rates within biomes worldwide. *Ecology Letters*, 11(10): 1065–1071.

Dijkstra, F.A. West, J.B. Hobbie, S.E. and Reich, P.B. (2009). Forest Ecology and Management Antagonistic effects of species on C respiration and net N mineralization in soils from mixed coniferous plantations. *Forest Ecology and Management*, 257: 1112–1118.

Fernando, M. and Bandeira, S. (2009). Litter fall and decomposition of mangrove species *Avicennia marina* and *Rhizophora mucronata* in Maputo Bay, Mozambique. *Western Indian Ocean Journal of Marine Science*, 8(2): 173–182.

Gao, J. Kang, F. Li, T. Song, X. Zhao, W. Yu, X. and Han, H. (2015). Assessing the effect of leaf litter diversity on the decomposition and associated diversity of fungal assemblages. *Forests*, 6: 2371–2386.

Gartner, T.B. and Cardon, Z.G. (2004). Decomposition dynamics in mixed-species leaf litter. *Oikos*, 104: 230–246.

Guerrero-Ramírez, N.R. Craven, D. Messier, C. Potvin, C. Turner, B.L. and Handa, I.T. (2016). Root quality and decomposition environment, but not tree species richness, drive root decomposition in tropical forests. *Plant and Soil*, 404: 125-139.

Hättenschwiler, S. and Jørgensen, H.B. (2010). Carbon quality rather than stoichiometry controls litter decomposition in a tropical rain forest. *Journal of Ecology*, 98(4): 754–763.

Hattenschwiler, S. Tiunov, A. and Scheu, S. (2005). Biodiversity and litter deomposition in terrestrial ecosystems. *Annual Review of Ecology and Evolution*, 36: 191–218.

Hoorens, B. Stroetenga, M. and Aerts, R. (2009). Litter Mixture Interactions at the Level of Plant Functional Types are Additive. *Ecosystems*, 13: 90–98.

Hoorens, B. Coomes, D. and Aerts R. (2010). Neighbour identity hardly affects litter-mixture effects on decomposition rates of New Zealand forest species. *Oecologia*, 162: 479–489.

Jacob, M. Viedenz, K. Polle, A. and Thomas F.M. (2010). Leaf litter decomposition in temperate deciduous forest stands with a decreasing fraction of beech (*Fagus sylvatica*). *Oecologia*, 164: 1083–1094.

Jacobs, L.M. Sulman, B.N. Brzostek, E.R. Feighery, J.J. and Phillips, R.P. (2018). Interactions among decaying leaf litter, root litter and soil organic matter vary with mycorrhizal type. *Journal of Ecology*, 106(2): 502–513.

Knecht, M.F. and Göransson, A. (2004). Terrestrial plants require nutrients in similar proportions. *Tree Physiology*, 24: 447–460.

Li, Q. Zhao, G. Cao, G. Zhang, X. and Liu, Z. (2020). Non-additive Effects of Leaf Litter Mixtures from *Robinia pseudoacacia* and ten Tree Species on Soil Properties. *Journal of Sustainable Forestry*: 1-14.

Liu, P. Sun, O.J. Huang, J. Li, L. and Han, X. (2007). Non-additive effects of litter mixtures on decomposition and correlation with initial litter N and P concentrations in grassland plant 20 species of northern China. *Biology and Fertility of Soils*, 44: 211–216.

Mao, B. Mao, R. and Zeng, D.H. (2017). Species diversity and chemical properties of litter influence non-additive effects of litter mixtures on soil carbon and nitrogen cycling. *PLoS ONE*, 12(7): 1-19.

Prescott, C.E. (2005). Do rates of litter decomposition tell us anything we really need to know ? *Forest Ecology and Management*, 220: 66–74.

Otsing, E. Barantal, S. Anslan, S. Koricheva, J. and Tedersoo, L. (2018). Litter species richness and composition effects on fungal richness and community structure in decomposing foliar and root litter. *Soil Biology and Biochemistry*, 125: 328–339

Purahong, W. Kapturska, D. Pecyna, M.J. Schulz, E. Schloter, M. Buscot, F. … and Kruğer, D. (2014). Influence of different forest system management practices on leaf litter decomposition rates, nutrient dynamics and the activity of ligninolytic enzymes: A case study from Central European forests. *PLoS ONE*, 9(4): 1–11.

Schwarz, B. Dietrich, C. Cesarz, S. Scherer-Lorenzen, M. Auge, H. Schulz, E. and Eisenhauer, N. (2015). Non-significant tree diversity but significant identity effects on earthworm communities in three tree diversity experiments. *European Journal of Soil Biology*, 67: 17–26.

Stephen, E.A. Evans, K.D. and Akwasi, A.A. (2020). Effects of *Faidherbia albida* on some important soil fertility indicators on agroforestry parklands in the semi-arid zone of Ghana. *African Journal of Agricultural Research,* 15(2): 256–268.

Waring, B.G. (2012). A Meta-analysis of Climatic and Chemical Controls on Leaf Litter Decay Rates in Tropical Forests. *Ecosystems*, 15(6): 999–1009.

Wolfe, B.T. Sperry, J.S. and Kursar, T.A. (2016). Does leaf shedding protect stems from cavitation during seasonal droughts? A test of the hydraulic fuse hypothesis. *New Phytologist*, 212(4): 1007–1018.

Zeng, D.H. Mao, R. Chang, S.X. Li, L.J. and Yang, D. (2010). Carbon mineralization of tree leaf litter and crop residues from poplar-based agroforestry systems in Northeast China: A laboratory study. *Applied Soil Ecology*, 44: 133–137.

Zhang, D.Q. Hui, D.F. Luo, Y.Q. and Zhou, G.Y. (2008). Rates of litter decomposition in terrestrial ecosystems: global patterns and controlling factors. *Journal of Plant Ecology*, 1(2): 85–93.

Zhang, J. Li, H. Zhang, H. Zhang, H. and Tang, Z. (2021). Responses of Litter Decomposition and Nutrient Dynamics to Nitrogen Addition in Temperate Shrublands of North China. *Frontiers in Plant Science*, 11: 1–10.

Zhang, J. Li, J. Fan, Y. Mo, Q. Li, Y. Li, Y. Li, Z. and Wang, F. (2020). Effect of nitrogen and phosphorus addition on litter decomposition and nutrients release in a tropical forest. *Plant and Soil*, 454(1): 139–153.