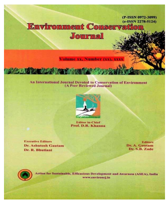
Journal homepage: https://www.environcj.in/

Environment Conservation Journal

ISSN 0972-3099 (Print) 2278-5124 (Online)



Pattern of litterfall production and nutrient addition in soil through litterfall by different tree species: A review

Pankaj
Department of Soil Science, CCS Haryana Agricultural University, Hisar, India

Krishan Kumar Bhardwaj ✉
Department of Soil Science, CCS Haryana Agricultural University, Hisar, India

Rajni Yadav
Department of Soil Science, CCS Haryana Agricultural University, Hisar, India

Vishal Goyal
College of Agriculture, Kaul, CCS HAU, Hisar, Haryana, India

Manoj Kumar Sharma
Department of Soil Science, CCS Haryana Agricultural University, Hisar, India

ARTICLE INFO

Received : 26 July 2023
Revised : 16 November 2023
Accepted : 24 November 2023

Available online: 15 December 2023

Key Words:
Agroforestry
Litter Decomposition
Litterfall, Nutrient Addition
Nutrient Cycling
Soil

ABSTRACT

Innutrient dynamics, an extremely valuable resource is litterfall. It is crucial to the dynamics of soil nutrients, the characteristics of soil, and the transfer of energy. In an agroforestry system, decomposition and litter fall are the two key processes that contribute to soil enrichment. In addition to affecting soil characteristics and ecology, litter fall in soil has a significant impact on carbon sequestration. The type of tree, the management methods, and the quantity and quality of litter all affect how much the soil is enriched. The complicated ecophysiological process of litterfall is influenced by both internal and external variables. Other significant causes of leaf fall include variations in weather and photoperiod as well as internal plant characteristics like age of leaf or potential endogenous rhythams. Nutrients are converted as a result of decomposition of different components of litter, and their release is influenced by the content of the litter, moisture, activity of microbes, C:N, temperature, and other variables. Litterfall therefore contributes to the long-term maintenance of nutrient levels in forest ecosystems and has been a primary research focus for a better understanding of soil fertility, site productivity, and forest services.

Introduction

Our capacity to meet food demands is threatened by the rapidly rising human population, the shrinking amount of cropland, and the declining fertility of the soil. In recent years, interest in sustainable farming practises like agroforestry has grown. Area under agroforestry is 25.32 million ha, or 8.2% of the total land area in India (Dhyani *et al.* 2013). Due to their short rotation, rapid growth, and high market value, certain tree species, including poplar (*Populus deltoides*) and eucalyptus (*Eucalyptus tereticornis*), are significant in agroforestry. So, these species have now been planted on degraded ground. In agricultural environments, the planting of specific tree species may reduce crop failure rates while also enhancing soil fertility (Chen *et al.,* 2019, Kumar *et al.,* 2017). By fixing nitrogen, absorbing nutrients from deeper soil layers, and producing and decomposing tree biomass, trees increase the fertility of the soil (Nair, 2011). Litter, leaf litter, or tree litter is any dead plant material that has fallen to the ground, including leaves, bark, needles, and twigs. Litter offers habitat to plants, microbes, and small animals. Nutrients are released into the ecosystem as litter breaks down. Humus is the fraction of the litter that takes longer to break down. The ecological stability of a wooded ecosystem depends fundamentally on the presence of leaf litter. For the majority of terrestrial ecosystems, the amount and pattern of litterfall influences the cycling of nutrient, the fertility of the soil, and primary production because leaf litter serves as a crucial link between vegetation and soils

Corresponding author E-mail: *krishansoils@gmail.com*
Doi:https://doi.org/10.36953/ECJ.24592671

and enables nutrients to be returned to the soils. (Fontes *et al.,* 2014, Becker *et al.,* 2015). Additionally, root extension and crown expansion aid in the topsoil's organic matter buildup, which enhances the soil's qualities in the root zone (Mukhopadhyay *et al.,* 2016). The cycling of carbon and nutrients are among the main biological processes that are enabled by the breaking down of plant litter. (Cornwell *et al.,* 2008). Besides this, litter production is reliant on the structural features of the vegetation, such as tree number, dimensions, and diversity of species which offers valuable insight into how an ecosystem functions, specifically in relation to the incorporation of soil organic carbon, the dynamics of decomposition, and the cycling of nutrients (Argao *et al.,* 2009). Litterfall accounts for an estimated 5% (43 Pg C) of the total worldwide forest carbon pool, transferring around one-third of the yearly carbon intake to the soil surface (Leitner *et al.,* 2016, Neumann *et al.,* 2018, Pan *et al.,* 2011). The Intergovernmental Panel on Climate Change (IPCC) lists litter carbon as being one of the five carbon pools in ecosystems of forests, in addition to aboveground biomass, belowground biomass, dead wood, and organic soil, in the yearly national greenhouse gas (GHG) inventories. (Eggleston *et al.,* 2006). Abiotic and biotic factors such as geographic location (e.g., latitude, longitude, and altitude), climate conditions (e.g., temperature and precipitation), and the structure of the vegetation (e.g., forest category, stand age, species, density, height, and diameter at breast height) all impacts litterfall production. (Starr *et al*., 2005, Chave *et al.,* 2010, Guo *et al.,* 2019, Kirman *et al.,* 2007, Quadros, 2019). According to earlier research (Martinez-Alonso *et al.,* 2007, Zhang *et al.,* 2014, Bhatti and Jassal, 2015), whereas climate-related characteristics, particularly temperature and precipitation, are the main drivers of litterfall generation, their consequences vary among regions and forest types. A common nondestructive method of determining the dynamics of airborne biomass is litterfall collecting. A significant source of nitrogen flow to soil is the production of leaf material. Important processes for transferring carbon and other nutrients from the above-ground system to the below-ground system in forests include litterfall and its subsequent decomposition. Through the transformation of organic components into inorganic elements that the plants can re-absorb, these activities represent important steps in the cycling of nutrients. Climate factors including temperature and precipitation as well as different forest types have been reported to have an impact on litter quality in terms of nitrogen, phosphorus, and potassium concentration. Different tree species produce litterfall and release nutrients in different ways. Additionally, litterfall alters the soil's physical and chemical characteristics, microbial activity, and variety of the soil's fauna and flora through the addition of organic matter and nutrients. Litterfall therefore contributes to the long-term maintenance of nutrient levels in forest ecosystems and has been a primary research focus for a better understanding of soil fertility, site productivity, and forest services.Only 2.86 percent of known forests were present in the primarily agricultural state of Haryana at the time of its founding. Agroforestry in the state at the time consisted of a few naturally occurring trees on agricultural bunds, including *Prosopis cineraria*, *Eucalyptus tereticor*, *Dalbergia sissoo*, *Populus deltoids*, *Acacia nilotica*, and *Azadirachta indica* (Chaturvedi *et al.,* 2016). These trees offer shade to agricultural workers and bullocks/camels as well as insurance security during drought years and crop failures. The introduction of poplar through WIMCO-NABARD partnerships with a buy-back guarantee during the 1980s transformed Haryana for the development of agroforestry. Poplar's success in Haryana became the world's best example of commercial agroforestry. Since then, it has grown in significance and has extended to new regions of Haryana. The areas covered by agroforestry have grown even more after the introduction of clonal eucalyptus, *Melia* and *Ailanthus excelsa*. According to Giri *et al.* (2019), poplar-based agroforestry systems are a sustainable method of using land in northern India since they increase biomass, soil fertility, carbon content, and other ecosystem services. Due to its rapid growth pattern and rising demand in the pulp and paper industry, *Melia composite* is a viable agroforestry tree species for boundary and block plantations. It grows well with up to 4 dS/m of EC and well-drained soils with moderate soil fertility.

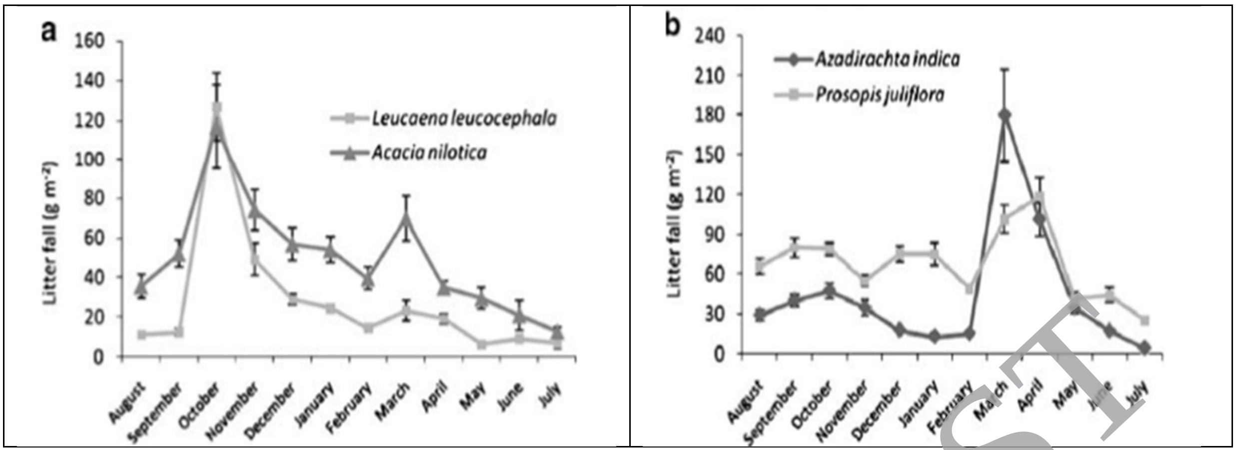


Figure 1: Leaf litterfall pattern of the four forest tree species (Jha and Mohapatra, 2010)

Effect of environmental variables on litter production

In areas with and without a dry season the dry and wet seasons are when litterfall in stands is at its highest, respectively. Litterfall output in ecosystems is highly correlated with rainfall seasonality (Becker *et al.,* 2015, Owusu-Sekyere *et al.,* 2006, Muoghalu and Odiwe, 2011). In particular, low air humidity, high temperature, and their interplay reduce litterfall by promoting the generation of abscisic acid in cocoa agroforestry systems (Dawoe *et al.,* 2010, Yang *et al.,* 2003, Triadiati *et al.,* 2011). Elevation, wind, and foliar diseases can all have an impact on leaf litterfall (Mamani-Pati *et al.,* 2012, Becker *et al.,* 2015). According to Kumar 2008, Domnguez *et al.* 2014, Muoghalu and Odiwe 2011, soil quality and management affect the quantity and the kind of the litter produced by an ecosystem. Because of faster biomass accumulation and/or a lower rate of nutrient absorption from litter before abscission, stands on fertile soils produce more high-quality litter than stands on poor soils (Kumar 2008, Fontes *et al.,* 2014). According to Wood *et al.* 2007, the quantity of litterfall, the quality of the leaf litter, the velocity of decomposition, and nitrogen mineralization are all factors that affect soil fertility. Because plants in natural systems, like forests, primarily rely on nutrient cycling to meet their nutritional needs, species variety and composition, as well as moisture availability, are used to control supply rate of nutrient and limitation of nutrient (Kumar 2008, Becker *et al.,* 2015, Wood *et al.,* 2007).

Effect of environmental variables on litter dynamics

There are three main ways that decomposition take place, (1) breaking down of litter in smaller fragments; (2) the dissolution of substances that are soluble in the soil; (3) the breakdown by decomposer organisms (Hattenschwiler and Jorgensen, 2010; Giebelmann *et al.* 2013).The environment, climate, and soil characteristics such as the soil's chemical makeup and physical structure, which indirectly regulates temperature and humidity, all have an impact on how quickly leaf litter decomposes in the soil (Rawat and Nautiyal 2009, Aravena *et al.,* 2002). For instance, due to the increased microbial decomposer populations and the microclimatic circumstances that support stand-specific litter decomposition, the amount of litter decomposition is greatly impacted by the organic forest top soil (Hayes and Holl, 2003). The rate of decomposition of litter is also greatly influenced by the soil's pH, temperature, and NH_4-N content. Temperature, moisture, and other microclimate elements may also have an impact on the breakdown rate of litter. Several publications claim that the process of decomposition of litter was sluggish in the cold and quick when it rained (Tripathi *et al.,* 2009, Devis and Yadav 2007), and the main causes for the faster litter decomposition rate during the rainy season may be the presence of sufficient rainfall, suitable moisture, and higher micro-fungal populations. Due to heavy rainfall, moist soil, and a high microbial load. Kumar *et al.* 2010, also came to the same conclusion that there is a high rate of litter

Table 1: Chemical characteristics of the litter of the different tree species (Verma *et al.,* 2022)

Parameter	N(%)	P (%)	K (%)	Ca (%)	Mg (%)	Cellulose (%)	Lignin (%)	Carbon (%)	C:N	L:N	C:P	N:P
Propsopis cineraria	2.21a	0.24a	0.71a	2.28a	0.58b	20.38b	11.68b	43.17ab	19.66b	5.33c	177.19a	9.04a
Hardwickia binata	1.41b	0.21a	0.56a	1.99a	0.67ab	25.81a	13.88a	43.85a	32.82a	13.88a	212.87a	6.58b
Tecomella undulata	2.31a	0.25a	0.51a	1.13b	0.98a	11.20c	9.30c	42.07b	19.91b	9.30b	172.40a	8.62a

decomposition and an increase in weight loss in rainy seasons. Even though this assertion should be evident, there is ongoing discussion regarding which climate index may most accurately forecast degradation rates. A number of scholars (including Magid *et al.,* 2002, Joffre *et al.,* 2001) strongly criticize this idea and claim that the correlation between real evapotranspiration and litter decomposition does not offer accurate indicators of decay rates. Furthermore, litter decomposes more quickly than its original location than any other plant cover environment (Chapman and Koch, 2007). For instance, conifer habitat decomposes more slowly than broadleaved habitat (Aravena *et al.,* 2002, Rawat and Nautiyal, 2009). When compared to higher altitudes, litter decomposes more quickly at lower elevations depending on the type of vegetation there (Veen *et al.,* 2015). Additionally, soil N concentration, soil organic matter content, fungal, bacterial ratio soil C:N and C:P all lowered the rate of litter breakdown (Veen *et al.,* 2015, Parsons *et al.,* 2014).

Importance of litterfall production

In agroforestry systems, decomposition of litter and litterfall are important nutrient recycling vectors. Woody perennials produce litter that enriches the soil with nutrients and gives decomposers the ingredients they need to reduce complex dead organic matter to simple mineral forms. These agroforestry activities contribute nutrients to the soil, replenishing its fertility (Notaro *et al.,* 2014, Yadav *et al.,* 2008). The rate of litter breakdown is influenced by the relationship between the soil biota, variations in the climate and litter quality. Age and species variations, site features, seasonal fluctuations, and tree management practices, as well as tree base area and stand age are some of the factors that determine litterfall rates (Kumar, 2008). The practical understanding of the consequences of litter is well established in many traditional agricultural methods. Plant litters have been used for a variety of things, such as mulching in low-tech agriculture, gardening, and modern horticulture (Gartner and Cardon, 2006), protecting against weed infestation (Cornwell *et al.,* 2008), preventing soil freezing and soil erosion (Cornwell *et al.,* 2008), improving mine reclamation (Giebelmann *et al.,* 2013), preserving moisture and reducing evapotranspiration, and enhancing the function of the forest ecosystem (Cornwell *et al.,* 2008). In forest ecosystems, nitrogen cycling directly influences productivity by making nutrients available for plant development (Krishna and Mohan, 2007). Primary production is typically assessed by the creation of litter, which serves as the primary source of soil organic carbon (SOC) and the cycling of plant nutrients. In the forest ecosystem, litter is another measure of primary production in addition to tree heights and diameters.

Temporal litterfall production by different tree species

Under semi-arid conditions of Haryana, Bhardwaj *et al.* 2016 studied the effect of tree (5*4, 10*2 and 18*2*2 m) different trees spacing on litterfall production in popular based agroforestry system and observed that litterfall under 5*4 m spacing was significantly higher by 2.48 and 1.84 times as compared to 10*2 and 18*2*2 m, respectively.

For three important agroforestry tree species growing in the dry western region of India, *Prosopis cineraria*, *Tecomella undulata* and *Hardwickia binata*, Verma *et al.* 2022 investigated litterfall production, decomposition, and nutrient release. *H. binata* (9.44 Mg/ha/yr) exhibited the highest litterfall, being followed by *P. cineraria* (8.94 Mg/h/yr) and *T. undulata* (3.74 Mg/h/yr). *P. cineraria*, *T. undulata*, and *H. binata* are the plants that drop their leaves most frequently in the winter and summer, respectively.

In Zambia, Yengwe *et al.* (2018) estimate *Faidherbia* tree litterfall patterns and nutrient deposition from various age classes. From 8-, 15-, and 22-year-old trees, the average amount of leaf litterfall was 1.6, 1.7, and 3.8 t DM/h, respectively. With this amount of litterfall, there might be an annual carbon and nutrient deposition of 0.7-1.6 t C/h, 34-83 kg N/h, 1.8-4.3 kg P/h, and 10-26 kg K/h. Compared to litterfall from 8- and 22-year-old trees, litterfall from 15-year-old trees exhibited higher concentrations of P and K. When compared to litterfall from 8- and 15-year-old trees, the C/N ratio of 22-year-old trees' litter was intermediate.

Negash and Starr (2021) investigated the decomposition of six different tree species litter in response to inputs of litterfall carbon on native agroforestry farms in southern Ethiopia. They noted that, aside from C and Mg concentrations, there were notable variations in the chemical composition of the litterfall (original litter material) across the species. In comparison to the other species, *C. macrostachyus*, *E. brucei* and *M. ferruginea* showed higher N concentrations and lower C/N ratios. The greatest Ca concentrations were also found in *C. macrostachyus* and *E. brucei*, however the difference between them and other species was not considerable. The lowest K concentrations were found in *M. indica* and *P. americana*, with a notable divergence from other species. The amount of magnesium did not considerably vary amongst the species.

In semi-arid regions of western Rajasthan, Yadav *et al.* (2008) reported significant seasonal variation in the litter production by various multipurpose trees. A significant pulse of litter production correlated with the winter months (November-February), and a period of decreased litterfall with the rainy season (July-October). In the Taran Taran district of Punjab, Rani *et al.* (2016) evaluated the litterfall production patterns of various tree species. They came to the conclusion that *P. deltoides* produced the highest amount of leaf litter (7.8 t/h), followed by *T. grandis* (1.83 t/h), and *E. tereticornis* (1.77 t/h), while *P. pyrifolia* produced the least (0.34 t/h).

Jha and Mohapatra (2010) investigated leaf litterfall in four prominent tree species from India's semi-arid region: *Leucaena leucocephala*, *Acacia nilotica*, *Azadirachta indica* and *Prosopis juliflora*. They demonstrated that all four species showed distinct seasonal swings but a yearly trend in leaf litterfall with a unimodal peak. *Leucaena leucocephala* and *Acacia nilotica* had leaf litterfall that varied from 6.5 (June) to 126.7 g/m^2 (October) and 12.8 (June) to 116.7 g/m^2 (October), respectively. *Azadirachta indica* and *Prosopis juliflora* had mean monthly leaf litterfalls of 4.5 (July) - 179.9 g/m^2 (March) and 25.8 (July) - 118.8 g/m^2 (April), respectively (Fig. 1). The amount of leaf litterfall varied greatly among the different forest species. Prosopis had much more leaf litter fall compared to other forest species being studied. Total leaf litterfall weight varied from 5.98, 5.38, and 3.31 Mg/ha/yr under *Acacia nilotica*, *Azadirachta indica* and *Leucaena leucocephala*, respectively, to as high as 8.13 Mg/ha/y in *Prosopis juliflora*. According to some writers fluctuations in temperature and photoperiod as well as within-plant characteristics like leaf age or potential endogenous rhythms are also significant causes of leaf fall. Given that all the species were of comparable age, the amount of leaf litterfall is closely related to canopy development, which is controlled by species nature (Carrera *et al.,* 2008).

Devi *et al.* (2021) investigated the pattern and overall litterfall production in eucalyptus-based agroforestry systems. They divided the litter into three categories: leaves, woody items, and other items. In the Kinnow + Eucalyptus + wheat system, the Eucalyptus tree supplied the most leaf litter (6.82 t/ha/annum), followed by the Kinnow tree (2.61 t/ha/annum), and the Kinnow tree (0.434 t/ha/annum) in the Kinnow + Wheat system. It was found that the months of November and December provided the most leaf litter, while May and June showed the least amount of litterfall.

The production of litterfall in the *Eucalyptus dunnii* Maiden stand was examined by Ludvichak *et al.* (2016). Leaf litter accounted for 61.57% of the overall litterfall production, which was 6.99 Mg/h/y. In comparison to the other litter components, such as twigs, thick branches, and miscellaneous, leaf litter had a higher nutritious content. Leaves, twigs, thick branches, and miscellaneous made up 61.57, 17.34, 13.83, and 7.26% of the total litterfall measured, respectively.

In a study, Kumar *et al.* (2017) observed that plantations of Prosopis cineraria, *Acacia senegal* and *Tecomella undulata* produced litter at rates of 16.1, 2.8, and 1.0 t/h, respectively. While *T. undulata* had the highest quantities of K, Fe, and Zn and P. cineraria had the highest amounts of Cu, *A. senegal* leaf litter had the highest concentrations of

P, Ca, Mg, & Mn. However, *P. cineraria* and *T. undulata* had higher and lower nutritional returns, respectively. Under all tree plantations, the sequence of nutrient return to soil was Ca > K > Mg > P > Fe > Mn > Zn > Cu.

Nutrient addition/release by different tree species

Satyawali *et al.* (2017) studied the monthly nutrient return via litterfall of *Eucalyptus camaldulensis* and *Melia azedarach* plantation in soil at different high density spacings. Maximum and minimum return of available macronutrients (kg/h) in soil was found in the months of March-April (5.58-6.10 N, 0.42-0.46 P, 1.64-1.79 K) and December-January (1.251.03 N, 0.10-0.08 P, 0.37-0.30 K) for *Eucalyptus camaldulensis* and December-January (7.148.81 N, 1.44-1.78 P, 5.19-6.41 K) and March-April (0.69-1.19 N, 0.14-0.24 P, 0.50-0.87 K) for *Melia azedarach*, respectively. The available NPK was found to be decreasing with the successive soil depths under all spacings and decreasing trend with the increase in planting density was observed which might be due to higher uptake of nutrients by more trees per unit area. Devi *et al.* (2021) examined the nutrient dynamics related to litterfall in the semi-arid region of Haryana. They noticed an increase in N, P and K concentrations due to tree species' leaf litter fall, and these nutrients' release into the soil as a result of their decomposition is a primary cause of the soil's improved N, P and K content. When compared to Kinnow leaf litter fall, the addition of N (94.1 kg/h) and P (19.1 kg/h) was substantially higher from Eucalyptus leaf litter fall; however, the addition of K (26.6 kg/h) was significantly higher from Kinnow litter fall (12.3 kg/h). Under alkaline soils of Haryana, Bhardwaj *et al.* (2016) analysed the nutrient concentration of macronutrients of litterfall from different spacing of 8 year old poplar based agroforestry systems. They revealed that there was no significant differences in the content of nitrogen, phosphorus and potassium in the leaves litterfall. Although, the content of nitrogen and phosphorus (1.32 and 0.15%) was highest in 5*4 m spacing whereas, Potassium content (0.64%) was highest under 18*2*2 m spacing.

Singh (2009) evaluated the poplar's nutrient concentrations in an agroforestry system under subtropical conditions at various ages and discovered that the concentrations of N, P, K, Ca, and S considerably reduced as plantation ages increased. Nutrient concentration was highest in plants that were one year old and lowest in those that were six years old. The dilution effect may be responsible for the decline in nutrient concentration with age. The concentration of Ca was highest (1.77-2.12%) and that of P was lowest (0.09-0.16%) among the major nutrients at different ages.

In poplar plantations with three spacings and two row directions, Singh *et al.* (2007) also found the highest concentration of calcium and the lowest concentration of phosphorus among the macronutrients. While litterfall was lowest (0.3 Mg/h) and highest (5.94 Mg/h) in plantations older than six years, respectively.

Yan *et al.* (2016) compared the nutrient concentration of senesced leaves of larch plantations and the secondary forest mainly dominated by *Quercus mongolica*, *Acer mono, Juglans mandshurica* and *Fraxinus rhynchophylla* plantations and reported significantly higher nutrient concentrations in *J. mandshurica* leaves among secondary forest plantations and lowest in *Larix spp*. The highest N, P, K, Ca, Cu, Zn concentration was recorded in *J. mandshurica* and Mg was in *A. mono* whereas lowest N, Ca, Mg, Cu was observed in *Larix* spp. and P, Zn was in *Q. mongolica*. Rani *et al.* (2016) evaluated the addition of nutrients by four distinct species and found that nitrogen (2.27%), potassium (1.90%), and phosphorous (0.32%) contributed the most nutrients through litter fall. *P. deltoides* (2.27%) and *P. pyrifolia* (1.15%) had the highest and lowest N input through leaf litter, respectively. K input (%) was highest in *T. grandis* leaves (0.32) and lowest in *E. tereticornis* (0.21). *P. deltoides* had the highest P input (%) through leaf litter (1.90), whereas *E. tereticornis* had the lowest (1.27).

According to Yadav and Bisht (2014), total annual deposition of litterfall under agri-horticultural systems was determined to be 2143.3 kg/h/yr, and the relative richness of nutrients in pecan nut tree litter fall was in the order of C>N>K>P. The total nutrient accumulation from the aforementioned pecan nut litter fall might be 901.91 kg of carbon per hectare per year, 57.44 kg N/h/y, 3.21 kg of phosphorus per hectare per year, and 43.29 kg of K/h/y. In the agri-horticultural systems, there was a large buildup of soil organic carbon and accessible NPK.

The concentration of N in the leaves was significantly different (p 0.05) between the species in the western arid region of India, according to Verma *et al.* (2022) and followed the order *T. undulata* > *P. cineraria* > *H. binata*, while the concentrations of P and K were not statistically different among the species. *P. cineraria* and *T. undulata* had the highest calcium and magnesium concentrations, respectively. The highest concentrations of cellulose, lignin, and carbon were found in the leaves of *H. binata*, followed by *P. cineraria*, while the lowest concentrations were found in *T. undulata*.

Between species, there were large differences in the C:N ratios, which ranged from 19.66 to 32.82. Although the differences in the C:P ratios amongst the species were not statistically significant, *H. binata* had the greatest C:P ratio (more than 200:1), followed by *P. cineraria*, and *T. undulata*. According to Table 1, the initial L:N and N:P ratios varied greatly among the various litter types, ranging from 5.33 to 13.88 for L:N and 6.58 to 9.04 for N,P. The traditional Eucalyptus-based agroforestry system's showed nutrient budget at various spacings was published by Kumar *et al.* (2021). They came to the conclusion that the leaves and branches were the main nutrient source. While in 2014–15, 61.5 m spacing, 33 m spacing, and 171 m spacing all yielded higher amounts of nitrogen (N) through leaf litter (54.04 and 53.05 kg/h, respectively). Out of which, the intercrops utilized a total of 44.01 kg/ha of nitrogen, 9.96 kg/h of phosphorus, and 68.65 kg/ha of potassium, respectively. Consequently, there are still 7.05 (kg/h) of phosphorus and 45.31 (kg/h) of nitrogen.

The recovery of nutrients by litterfall in a stand of *Eucalyptus dunnii* in a Pampa ecosystem is evaluated by Ludvichak *et al.* (2016) and concluded that the order of macro- and micro-nutrient concentration of leaf litter varied as Ca (12.52 g/kg) > N (7.76 g/kg) > K (3.77 g/kg) > Mg (2.43 g/kg)> S (0.78 g/kg)> P (0.52 g/kg) and Mn (1252.73 ppm) > Fe (106.52 ppm) > B (40.99 ppm) > Zn (12.44 ppm) > Cu (5.46 ppm) respectively. The same pattern was observed for nutrient return through litterfall.

Conclusion

The primary mechanism responsible for soil improvement in agroforestry systems is litterfall from trees. The growth pattern, age, density and canopy characteristics, as well as the environment, including temperature, all affect the quantity and quality of litterfall. The type of tree, the management techniques used, and the quantity and quality of litter all affect how much nutrient return (macro and micro nutrients) occurs in the soil. In order to research how different tree species affect soil enrichment, it is essential to obtain knowledge of the litterfall, nutrient content and prospective nutrient returns by different tree species.

Conflict of interest

The authors declare that they have no conflict of interest.

References

Aravena, J. C., Carmona, M. R., Perez, C. A., & Armesto, J. J. (2002). Changes in tree species richness stand structure and soil properties in a successional chronosequence in northern Chile Island. *Revista Chilena de Historia Natural,* 75, 339-360.

Argao, L. E. O. C., Malhi, Y., Metcalfe, D. B., Silva-Espejo, J. E., Jimenez, E., Navarrete, D., & Asquez, R. (2009). Above- and below-ground net primary productivity across net primary productivity across ten Amazonian forests on contrasting soils. *Biogeoscience,* 6, 2759–2778.

Becker, H., Pabst, J., Mnyonga, J., & Kuzyakov, Y. (2015). Annual litterfall dynamics and nutrient deposition depending on elevation and land use at Mt. Kilimanjaro. *Biogeoscience Discussion,* 2, 10031-10057.

Bhardwaj, K. K., Dhillon, R. S., Godara, A. S., Bangarwa, K. S., Sushil, K., & Sheokand, R. N. (2016). Effect of different spacings of poplar based agroforestry system on soil chemical properties and nutrient status in North-West India. *Indian Journal of Ecology,* 43(1), 312-317.

Bhatti, J. S., & Jassal, R. S. (2015). Long term aboveground litterfall production in boreal jack pine (Pinus banksiana) and black spruce (Picea mariana) stands along the Boreal Forest Transect Case Study in western central Canada. *Ecoscience,* 21(3–4), 301-314.

Carrera, A. L., Bertiller, M. B., & Larreguy, C. (2008). Leaf litterfall, fine-root production, and decomposition in shrub lands with different canopy structure induced by grazing in the Patagonian Monte, Argentina. *Plant Soil,* 311, 39-50.

Chapman, S. K., & Koch, G. W. (2007). What type of diversity yields synergy during mixed litter decomposition in a natural forest ecosystem? *Plant Soil,* 299, 153-162.

Chaturvedi, O. P., Mishra, P. K., & Kaushal, R. (2016). Agroforestry for natural resource conservation and sustainable production. *Agroforestry*, pp.15.

Chave, J., Navarrete, D., Almeida, S., Alvarez, E., Aragao, L. E. O. C., Bonal, D., Chatelet, P., Silva Espejo, J., Goret, J. Y., Hildebrand, P. V., Jimenez, E., Patino, S., Penuela, M. C., Phillips, O. L., Stevenson, P., & Malhi, Y. (2010). Regional and seasonal patterns of litterfall in tropical South America. *Biogeosciences,* 7, 43-55.

Chen, C., Liu, W., Wu, J., Jiang, X., & Zhu, X. (2019). Can intercropping with the cash crop help improve the soil physico-chemical properties of rubber plantations? *Geoderma,* 335, 149-160.

Cornwell, W. K., Cornlissen, 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., Bodegom, P.V., Brovkin, V., Chatain, A., Callaghan, T. V., Díaz, S., Garnier, E., Gurvich, D. E., Kazakou, E., Klein, J. A., Read, J., Reich, P. B., Soudzilovskaia, N. A., Vaieretti, M. V.,& Westoby, M. (2008). Plant species traits are the predominant control on litter decomposition rates within biomes worldwide. *Ecological Letter,* 11,1065-1071.

Dawoe, E. K., Isaac, M. E., & Quashie-Sam, J. (2010). Litterfall and litter nutrient dynamics under cocoa ecosystems in lowland humid Ghana. *Plant and Soil,* 330(1), 55-64.

Devi, S., Bhardwaj, K. K., Dhillon, R. S., Sharma, M. K., & Dahiya, G. (2021). Nutrient dynamics associated with leaf litter fall under agroforestry systems in semi-arid region of Haryana. *Indian Journal of Agroforestry,* 23(1), 13-17.

Devis, A. S., & Yadav, P. S. (2007). Wood and leaf litter decomposition of Dipterocarpus tuberculatus Roxb. in a tropical deciduous forest of Manipur, North East India. *Current Science,* 93, 243-246.

Dhyani, S. K., Handa, A. K., & Uma. (2013). Area under agroforestry in India, an assessment for present status and future perspective. *Indian Journal of Agroforestry,* 15(1), 1-11.

Dominguez, A., Bedano, C. J., Becker, A. R., & Arolfo, R. V. (2014). Organic farming fosters agroecosystem functioning in Argentinian temperate soils, evidence from litter decomposition and soil fauna. *Applied Soil Ecology,* 83, 170-176.

Eggleston, S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (2006). IPCC Guidelines for National Greenhouse Gas Inventories, vol. 5. Institute for Global Environmental Strategies (Eds), Hayama, Japan.

Fontes, A. G., Gama-Rodrigues, A. C., Gama-Rodrigues, E. F., Sales, M. V. S., Costa, M. G., & Machado, R. C. R. (2014). Nutrient stocks in litterfall and litter in cocoa agroforests in Brazil. *Plant Soil,* 383, 313-335.

Gartner, T. B., & Cardon, Z. G. (2006). Site of leaf origin affects how mixed litter decomposes. *Soil Biology and Biochemistry,* 38(8), 2307-2317.

Giebelmann, U. C., Martins, K. G., Brandle, M., Schadler, M., Marques, R., & Brandl, R. (2013). Lack of home-field advantage in the decomposition of leaf litter in the Atlantic rainforest of Brazil. *Applied Soil Ecology,* 49, 5-10.

Giri, A., Kumar, G., Arya, R., Mishra, S., & Mishra, A. K. (2019). Carbon sequestration in Populus deltoides based agroforestry system in northern India. *International Journal of Chemical Studies,* 7(1), 2184-2188.

Guo, Y., Chen, H., Mallik, A., Wang, B., Li, D., Xiang, W., & Li, X. (2019). Predominance of abiotic drivers in the relationship between species diversity and litterfall production in a tropical karst seasonal rainforest. *Forest Ecology and Management,* 449, 1-9.

Hattenschwiler, S., & Jorgensen, H. B. (2010). Carbon quality rather than stoichiometry controls litter decomposition in a tropical rain forest. *Journal of Ecology,* 98, 754-763.

Hayes, G. F., & Holl, K. D. (2003). Cattle grazing impacts on annual forbs and vegetation composition of mesic grasslands in California. *Conservation Biology,* 17(6), 1694-1702.

Jha, P., & Mohapatra, P. K. (2010). Leaf litterfall, fine root production and turnover in four major tree species of the semi-arid region of India. *Plant and Soil,* 326(1), 481-491.

Joffre, R., Agren, G. J., Gillon, D., & Bosatta, E. (2001). Organic matter quality in ecological studies, Theory meets experiment. *Oikos,* 93, 451–458.

Kirman, S., Strasberg, D., Grondin, V., Colin, F., Gilles, J., & Meunier, J.D. (2007). Biomass and litterfall in a native lowland rainforest, Marelongue reserve, La r´eunion island, Indian ocean. *Forest Ecology and Management,* 252(1-3), 257-266.

Krishna, M. P., & Mohan, M. (2017). Litter decomposition in forest ecosystems, a review. *Energy, Ecology and Environment,* 2(4), 236-249.

Kumar, B. M. (2008). Litter dynamics in plantation and agroforestry systems of the tropics - A review of observations and methods. In, Batish DR, Kohli RK, Jose S, Singh HP, editors. *Ecological Basis of Agroforestry*. Boca Raton (USA), CRC Press; pp 181–216.

Kumar, M., Joshi, M., & Todaria, N. P. (2010). Regeneration status of a sub-tropical Anogeissus latifolia forest in Garhwal Himalaya, India. *Journal of Forestry Research,* 21(4), 439-444.

Kumar, M., Kumar, P., Tewari, J. C., & Pandey, C. B. (2017). Changes in soil fertility under multipurpose tree species in Thar Desert of Rajasthan. *Range Management and Agroforestry,* 38(2), 274-279.

Kumar, T., Kumari, B., Arya, S., Yadav, V.K., & Kaushik, P. (2021). Estimation of the soil and plant nutrient budget of the traditional Eucalyptus based agroforestry system in different spacing. *Indian Journal of Traditional Knowledge,* 20(1), 253-261.

Leitner, S., Sae-Tun, O., Kranzinger, L., Zechmeister-Boltenstern, S., & Zimmermann, M. (2016). Contribution of litter layer to soil greenhouse gas emissions in a temperate beech forest. *Plant Soil,* 403(1-2), 455-469.

Ludvichak, A. A., Schumacher, M. V., Dick, G., Momolli, D. R., Souza, H. P. D., & Guimarães, C. D. C. (2016). Nutrient return through litterfall in a Eucalyptus dunnii Maiden stand in sandy soil. *Revista Árvore,* 40, 1041-1048.

Magid, J., Cadisc, G., & Giller, K. E. (2002). Short and medium term plant litter decomposition in a tropical Ultisol elucidated by physical fraction in a dual 13C and 14C isotope study. *Soil Biology and Biochemistry,* 34, 1273-1281.

Mamani-Pati, F., Clay, D. E., Clay, S. A., Smeltekop, H., & Yujra-Callata, M. A. (2012). The influence of strata on the nutrient recycling within a tropical certified organic coffee production system. *International Scholarly Research Notices*, Agronomy.

Martinez-Alonso, C., Valladares, F., Camarero, J., Arias, M. L., Serrano, M., & Rodríguez, Y. A. (2007). The uncoupling of secondary growth, cone and litter production by intradecadal climatic variability in a mediterranean Scots pine forest. *Forest Ecology and Management,* 253(1-3), 19-29.

Mukhopadhyay, S., Masto, R. E., Yadav, A., George, J., Ram, L. C., & Shukla, S. P. (2016). Soil quality index for evaluation of reclaimed coal mine spoil. *Science of the Total Environment,* 542, 540-550.

Muoghalu, J. I., & Odiwe, A. I. (2011). Litter production and decomposition in cacao (Theobroma cacao) and kolanut (Cola nitida) plantations. *Ecotropica,* 17(1), 79-90.

Nair, P. K. (2011). Agroforestry systems and environmental quality, Introduction. *Journal of Enviromental Quality,* 40(3), 784-790.

Negash, M., & Starr, M. (2021). Litter decomposition of six tree species on indigenous agroforestry farms in south-eastern Ethiopia in relation to litterfall carbon inputs and modelled soil respiration. *Agroforestry Systems,* 95(4), 755-766.

Neumann, M., Ukonmaanaho, L., Johnson, J., Benham, S., Vesterdal, L., Novotny, R., Verstraeten, A., Lundin, L., Thimonier, A., Michopoulos, P., & Hasenauer, H. (2018). Quantifying carbon and nutrient input from litterfall in european forests using field observations and modelling. *Global Biogeochemical Cycles,* 32(5), 784-798.

Notaro, K. A., Erika, V. M., Gustavo, P. D., Aline, O. S., & Patrícia, M. M. (2014). Agroforestry systems, nutrients in litter and microbial activity in soils cultivated with coffee at high altitude. *Scientia Agricola,* 71(2), 87-95.

Owusu-Sekyere, E., Cobbina, J., & Wakatsuki, T. (2006). Nutrient cycling in primary, secondary forests and cocoa plantation in the Ashanti Region, Ghana. *West African Journal of Applied Ecology,* 9(1), 1-9.

Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P., Kurz, W. A., Phillips, O. L., Shvidenko, A., Lewis, S.L., Canadell, J. G., Ciais, P., Jackson, R.B., Pacala, S.W., David McGuire, A., Piao, S., Rautiainen, A., Sitch, S., & Hayes, D. (2011). A large and persistent carbon sink in the world's forests. *Science,* 333(6045), 988-993.

Parsons, S. A., Valdez-Ramirez, V., Congdon, R. A., & Williams, S. E. (2014). Contrasting patterns of litterfall seasonality and seasonal changes in litter decomposability in a tropical rainforest region. *Biogeosciences,* 11, 5047-5056.

Quadros, A. F., Nordhaus, I., Reuter, H., & Zimmer, M. (2019). Modelling of mangrove annual leaf litterfall with emphasis on the role of vegetation structure. Estuarine. *Coastal and Shelf Science,* 218, 292–299.

Rani, S., Benbi, D. K., Rajasekaran, A., & Chauhan, S. K. (2016). Litterfall, decomposition and nutrient release patterns of different tree species in Taran Taran district of Punjab, India. *Journal of Applied and Natural Science,* 8(3), 1260-1266.

Rawat, N., & Nautiyal, M. C. (2009). Litter production pattern and nutrients discharge from decomposing litter in Himalayan alpine ecosystem. *New York Science Journal,* 2(6), 1554-0200.

Satyawali, K., Chaturvedi, S., & Bisht, N. (2017). Effect of high density Eucalyptus camaldulensis and Melia azedarach plantation on soil nutrients at different planting density. *International Journal of Communication Science,* 5(4), 827-831.

Singh, B. (2009). Return and release of nutrients from poplar litterfall in an agroforestry system under subtropical condition. *Journal of the Indian Society of Soil Science,* 57(2), 214.

Singh, B., Gill, R.I.S., & Kaur, N. (2007). Litterfall and nutrient return in poplar plantation varying in row directions and spacings. *Indian Journal of Agroforestry.* 9, 33-37.

Starr, M., Saarsalmi, A., Hokkanen, T., Merilac, P., & Helmisaari, H. S. (2005). Models of litterfall production for Scots pine (Pinus sylvestris l.) in Finland using stand, site and climate factors. *Forest Ecology and Management,* 205 (1–3), 215–225.

Triadiati, S., Tjitrosemito, E., Sundarsono, G., Qayim, I., & Leuschner, C. (2011). Litterfall production and leaf-litter decomposition at natural forest and cacao agroforestry in Central Sulawesi, Indonesia. *Asian Journal of Biological Science,* 4, 221-234.

Tripathi, O. P., Pandey, H. N., & Tripathi, R. S. (2009). Litter production, decomposition and physicchemical properties of soil in 3 developed agroforestry systems of Meghalaya, Northeast India. *African Journal of Plant Science,* 3(8), 160-167.

Veen, G. F., Sundqvist, M. A., & Wardle, D. A. (2015). Environmental factors and traits that drive plant litter decomposition do not determine home-field advantage effects. *Functional Ecology,* 29, 981-991.

Verma, A., Kumar, P., Soni, M. L., Pawar, N., Pradhan, U., Tanwar, S. P. S., & Kumar, S. (2022). Litter production and litter dynamics in different agroforestry systems in the arid western region of India. *Biological Agriculture & Horticulture,* 38(1), 40-60.

Wood, T. E., Lawrence, D., Clark, A. D. (2007). Determinants of leaf litter nutrient cycling in a tropical rain forest, soil fertility versus topography. *Ecosystems,* 9,700-710.

Yadav, R. P., & Bisht, J. K. (2014). Litter fall and potential nutrient returns from pecan nut (Carya illinoinensis) in agroforestry system in Indian Himalaya. *International Journal of Herbal Medicine,* 2(1), 51-52.

Yadav, R. S., Yadav, L., & Chhipa, B. R. (2008). Litter dynamics and soil properties under different tree species in a semi-arid region of Rajasthan, India. *Agroforestry Systems,* 73(1), 1-12.

Yan, T., Lü, X., Yang, K., & Zhu, J. (2016). Leaf nutrient dynamics and nutrient resorption, a comparison between larch plantations and adjacent secondary forests in Northeast China. *Journal of Plant Ecology,* 9(2), 165-173.

Yang, Y. S., Guo, J. S., Chen, G. S., He, Z. W., & Xie, J. S. (2003). Effect of slash and burning on nutrient removal and soil fertility in Chinese fir and evergreen broadleaved forests of midsubtropical China. *Pedosphere,* 13, 87-96.

Yengwe, J., Amalia, O., Lungu, O. I., & De Neve, S. (2018). Quantifying nutrient deposition and yield levels of maize (Zea mays) under Faidherbia albida agroforestry system in Zambia. *European Journal of Agronomy,* 99, 148-155.

Zhang, H., Yuan, W., Dong, W., & Liu, S. (2014). Seasonal patterns of litterfall in forest ecosystem worldwide. *Ecological Complex,* 20, 240-247.

Publisher's Note: ASEA remains neutral with regard to jurisdictional claims in published maps and figures.