Journal of Ecology and Environment

REVIEW

Open Access

Role of litter production and its decomposition, and factors affecting the processes in a tropical forest ecosystem: a review

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Abstract

In the forest ecosystems, litterfall is an important component of the nutrient cycle that regulates the accumulation of soil organic matter (SOM), the input and output of the nutrients, nutrient replenishment, biodiversity conservation, and other ecosystem functions. Therefore, a profound understanding of the major processes (litterfall production and its decomposition rate) in the cycle is vital for sustainable forest management (SFM). Despite these facts, there is still a limited knowledge in tropical forest ecosystems, and further researches are highly needed. This shortfall of research-based knowledge, especially in tropical forest ecosystems, may be a contributing factor to the lack of understanding of the role of plant litter in the forest ecosystem function for sustainable forest management, particularly in the tropical forest landscapes. Therefore, in this paper, I review the role of plant litter in tropical forest ecosystems with the aims of assessing the importance of plant litter in forest ecosystems for the biogeochemical cycle. Then, the major factors that affect the plant litter production and decomposition were identified, which could direct and contribute to future research. The small set of studies reviewed in this paper demonstrated the potential of plant litter to improve the biogeochemical cycle and nutrients in the forest ecosystems. However, further researches are needed particularly on the effect of species, forest structures, seasons, and climate factors on the plant litter production and decomposition in various types of forest ecosystems.

Keywords: Biogeochemical cycle, Ecosystem functions, Litterfall, Litter decomposition, Sustainable forest management, Tropical forest

Background

Among the various components of the plant-soil system, nutrient cycling is directly linked to productivity in terrestrial ecosystems (Szanser et al. 2001). Litter is directly involved in plant-soil interaction because it helps to incorporate carbon and nutrients from plants into the soil (Cuevas and Lugo 1998). Carbon and nutrient cycling are the key ecosystem processes, which are driven by the decomposition of plant litter (Cornwell et al. 2008). Furthermore, based on the structural parameters of vegetation, such as tree abundance, size, and species diversity, litter production provides an important information on ecosystem functioning, i.e., it relates to soil organic carbon incorporation, decomposition dynamics, and nutrient cycling (Argao et al. 2009).

The quantity and quality of litter determine the functioning of the forest ecosystem (Argao et al. 2009) and are also essential for balanced ecosystem processes. (Argao et al. 2009). In tropical forests, decomposing leaves pass through three main stages: nutrient release, net immobilization, and net release (Vitousek and Sanford 1986). Soil properties and leaf litter quality are among the major factors, which determine the decomposition rate of litter (Zhang et al. 2014). Furthermore, the litter production pattern between ecosystems varies depending on elevation, latitude, soil fertility, stand structure, climate, and tree species composition (Parsons et al. 2014; Becker et al. 2015). On the other hand, in most tropical forests, the amount of litter on the soil

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varies depending on the seasons (Zhang et al. 2014), and the litterfall pattern could be unimodal, bimodal, or irregular (Scheer 2009).

The role of plant litter in forest ecosystem functioning and resilience is not well known and is not normally considered in the tree selection processes for rehabilitation projects of degraded area, and in sustainable forest ecosystem management, in general. Therefore, the aim of this review paper is to summarize the state-of-the-art on the functional significance of plant litter and its decomposition in forest ecosystems. Accordingly, the paper will highlight and focus on the following major points: how the plant litters are variable within and among forest ecosystems, how the variability in litter quality and decomposition affects the functioning of the forest ecosystems, and what major factors determine the litter production and decomposition in forest ecosystems.

Importance of litter production and its decomposition processes in the functioning of forest ecosystem

In many traditional agricultural practices, the practical knowledge of the effects of litter is well known. For example, plant litters were used for the following purposes: for mulching in low-technology agriculture, gardening and modern horticulture (Gartner and Cardon 2006), preventing soil freezing and soil erosion (Cornwell et al. 2008), protecting weed infestation (Cornwell et al. 2008), improving mine reclamation (Giebelmann et al. 2013), conserving moisture and reduce evapotranspiration, and improving the forest ecosystem function (Cornwell et al. 2008).

Nutrient cycling is directly related to productivity in forest ecosystems by providing available nutrients for plant growth (Table 1) (Krishna and Mohan 2007). Since litter is the main source of soil organic carbon (SOC) and plant nutrient cycling, primary production is usually evaluated through litter production (Vitousek 1982). Furthermore, in the forest ecosystem, further to tree heights and diameters, litter is an indicator of primary production (Vitousek 1982). As Fig. 1 shows, in spite of the fact that the decomposition of plant litter determines the carbon cycle, it controls the concentration of carbon dioxide (CO_2) in the atmosphere, which in turn, has an influence on the global climate (Swift et al. 1979; Krishna and Mohan 2007).

The interaction of decomposers, litter quality, and abiotic factors will result in the decomposition of litter, in which the litter is broken down into smaller pieces, and finally mineralized into inorganic compounds (Cadish and Giller 1997; Chapman and Koch 2007). The changes of litter over time can be attributed to the effects of the following major processes (Mishra et al. 2004; Chapman and Koch 2007; Lira et al. 2007).

a) Leaching is the removal of soluble material to a lower soil layer for further processing by decomposers.
b) Fragmentation is creating new surface areas for decomposers through physical breakdown of large pieces of litter into smaller ones.
c) Chemical alteration is the chemical change of the litter and occurs when decomposers recognize the molecules or use only a part of the molecule during the production of decomposer biomass.

During the litter decomposition process, the chemical composition of litter changes due to degradation of structural and soluble compounds (Vitousek and Sanford 1986; Argao et al. 2009). Soil fauna and micro-organism play a great role in the decomposition process, in which the soluble nutrients may be initially leached and subsequently either mineralized or immobilized depending on the demands of the decomposer communities (Mishra et al. 2004; Krishna and Mohan 2007). Since organic carbon in the litter is the primary energy source

Table 1 Direct and indirect effect of litter production and decomposition on the physical and chemical environment

Effect	Mechanism
• Reduce the thermal amplitude in the soil	• Accumulation of litter intercept light, shading seeds and seedlings, which in turn decreases soil temperature (Krishna and Mohan 2007).
• Reduce evapotranspiration (ET) from the soil	• Reduce maximum soil temperatures • Creates a barrier to water vapor diffusion (Argao et al. 2009).
• Diminish water availability	• Litter may retain a large proportion of rainfall (Vitousek and Sanford 1986).
• Reduce seed germination and seedling emergences	• Creates a barrier for sprouts and seedling emergence and prevent seeds to reach soils (Chapman and Koch 2007).
• Patchy accumulation of plant litter may alter community structure	• Litter of one species may affect the performance of a second species (Chapman and Koch 2007). • Litter produced by one species may alter the interaction between a second and a third species (Melo et al. 2013).
• Increase CO_2 efflux	• Microbial decomposition can add more than 20% CO_2 efflux to the soil (Krishna and Mohan 2007).
• Increase nutrient return to the soil	• Litterfall is a crucial pathway for nutrient return to the soil (Krishna and Mohan 2007).

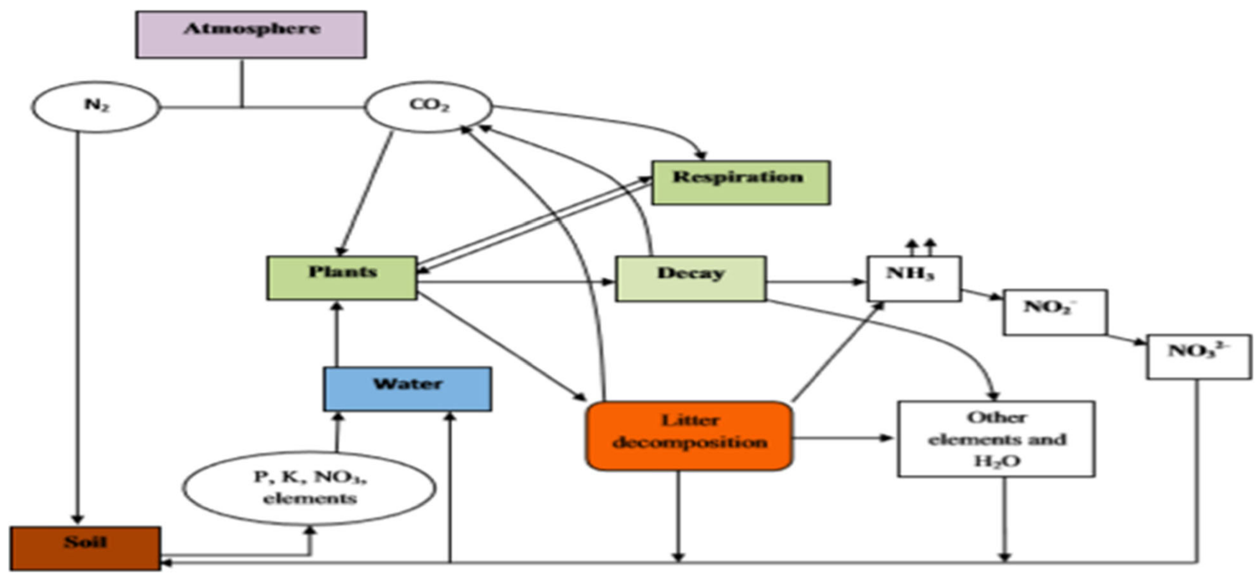

Fig. 1 The role of litter degradation in the biogeochemical cycles (from Krishna and Mohan 2007)

for decomposers, the amount of C in the litter decreases over time; however, the loss of C in the litter is determined by the growth rate and efficiency of decomposers (Liu 2012; Giebelmann et al. 2013). The main factors that determines the growth rate and efficiency of decomposers are nutrient availability, temperature, water availability, and litter quality (Perez-Harguindeguy et al. 2000; Hattenschwiler and Jorgensen 2010; Giebelmann et al. 2013).

Furthermore, during the decomposition of plant litter, the conversion of dead organic matter into carbon dioxide (CO_2), and the supply of nutrients for microbes and plants are the vital ecosystem processes (Cadish and Giller 1997; Mishra et al. 2004). An addition of litters to the different layers of soil affects soils' water and nutrients absorption capacity (Cadish and Giller 1997; Chaubey et al. 1988), thereby enhance the water and nutrients absorption capacity of soils. High diversity of tree species in the forest ecosystem could increase organic carbon and C/N ratio in the soil (Vitousek and Sanford 1986). Furthermore, compared to monocultures, diverse mixtures have higher litter yields (both in quantity and quality), which in turn could increase the aboveground productivity and carbon sock (Chapman and Koch 2007; Wiebe 2014).

N and C dynamics during litter decomposition follows different patterns, i.e., since fresh litters usually contain little N compared to the decomposers need, the decomposers will be forced to immobilize nitrogen from the surrounding environment (Swift et al. 1979; Berg and Laskowski 2006). However, through time, the N concentration will exceed the decomposers' demand and the N:C concentration will be higher, which implies the start of N mineralization process and assimilation of substrate (Laganiere et al. 2010). Therefore, N:C determines the litter decomposition process and the N dynamics.

As Table 1 shows, litter production and its decomposition processes have a direct and indirect effect in the functioning of the forest ecosystem. Litter decomposition provides readily available nutrients to plants because it incorporates organic carbon into soil through nutrient cycling processes. Furthermore, litter plays a great role in improving soil quality by transferring nutrients from the aboveground biomass to the soil (Vitousek and Sanford 1986), increasing the cation exchange capacity and water holding capacity of the soil (Argao et al. 2009). Litter decomposition alters soil properties such as cation exchange capacity (CEC) and the stability of soil organic carbon. For example, Scheer (2009) reported that the decline in forest litter production, which is induced by climate change, has resulted in the decrease of nutrient concentrations and organic matter content in the soil.

Factors affecting litter production in forest ecosystems

As Tables 2 and 3 show, the litter production and accumulation in forest ecosystem are affected by several environmental as well as anthropogenic factors, and each of them have a significant effect either individually and/or in an interactive way.

Anthropogenic and natural disturbance

It is obvious that forests have complex systems with multiple attributes, and these attributes interact with each other across wider geographical regions (Scheer

Table 2 Summary of the major biotic and abiotic factors affecting in situ litter production

Environmental factors	Effects
• Climate	• Rainfall and length of the growing season determine the in situ litter production (Melo et al. 2013).
• Soil fertility	• During decomposition process nitrogen (N), phosphorous (P), and calcium (Ca) will be released from plant litter and are accessible for plants and microbial uptake, which in turn could increase the in situ litter production (Cadish and Giller 1997).
• Actual evapotranspiration	• Litter production is explained more by actual evaporation compared to latitude and potential evapotranspiration (Melo et al. 2013).
• Wind and storms	• Winds and storms may affect the speed of transformation of plant organ into litter (Cadish and Giller 1997).
• Time lag	• The time lag between the formation of plant organ and its deposition determines in situ litter production (Franklin et al. 2002).
• Herbivores	• Though consumption usually reduces the standing biomass, herbivores may either increase or decrease the production of litter (Gonzalez et al. 2005).

2009; Krishna and Mohan 2007). Usually, stands with less structural complexity generally have lesser species diversity and promote lesser stability and ecosystem functioning in comparison with stands with higher structural complexity (Argao et al. 2009; Scheer 2009). Anthropogenic disturbances such as crop and livestock farming, logging, fire, and forest cutting for firewood have a great potential to degrade the composition and structural attributes of forests (Mishra et al. 2004). Furthermore, both anthropogenic and natural disturbances can degrade the quantity and quality of annual litterfall, litter depth, stand basal area, volume of coarse woody debris, and density of understory (Mishra et al. 2004).

The level of disturbances between sites will affect the proportion of litter fraction (for example, leaf litter, reproductive parts, and twigs) (Seta and Zerihun 2018). Less disturbed sites have higher annual litterfall production compared to highly disturbed sites (Wiebe 2014; Seta and Zerihun 2018). The continuous removal of logs for firewood and cutting of snags will result in lower structural complexity (Wiebe 2014). The opening of roads for timber extraction and logging practices will also contribute to the elimination and alteration of the understory (Mishra et al. 2004; Melo et al. 2013).

Past researches have also shown that snags were three to five times less dense in logged plots compared to undisturbed plots (Mishra et al. 2004; Wiebe 2014). Aravena et al. (2002) also indicated that compared to plots with combined presence of fire and logging, the undisturbed plots have a higher basal area. The presence of livestock solely or in combination with other disturbances has a strong effect on stand structure and their attributes such as litter depth, basal area, and understory density (Franklin et al. 2002; Gonzalez et al. 2005). Livestock had also a stronger negative effect on forest regeneration, understory structure by grazing, and trampling the herbaceous layer (Gonzalez et al. 2005). The quantity of biomass for litter conversion would be reduced due to the livestock grazing of plant biomass, which are located on the above ground (Franklin et al. 2002; Gonzalez et al. 2005). Hayes and Holl (2003) have also reported that litter depth was higher in ungrazed sites compared to grazed sites.

Climatic variables and seasonal variations

The exchange of carbon from terrestrial to the atmosphere is highly influenced by the litterfall production and may vary depending on the seasons (De Weirdt et al. 2012; Zhang et al. 2014). The dynamics of ecosystem carbon and nutrient cycling is highly influenced by

Table 3 Summary of factors affecting the pattern of litter accumulation

Factors	Referred examples
• In situ litter production	• The productivity of plant community at a site has a strong influence on in situ litter production (Bray and Gorham 1964).
• Deposition of litter from outside the system	• The deposition of exogenous litter and the removal of the native litter have a strong impact on litter accumulation (Becker et al. 2015).
• Litter destruction by physical and biotic agents	• Physical and chemical degradation, decomposition, and heterotrophic consumption may reduce the mass of in situ litter accumulated (Andren and Paustian 1987; Olson 1963). • Decomposition rates vary greatly among ecosystems (Andren and Paustian 1987).
• Removal of litter	• The main cause for the disappearance of litter from any open sites is the removal of fragmented litters from open sites due to runoff, geometry of shrubs, and wind and water flow (Becker et al. 2015).
• Temporal variations	• Accumulated litter may vary due to transient environmental fluctuation on successional and seasonal time scales (Andren and Paustian 1987; Olson 1963).

the seasonal variation of the litterfall (Franklin et al. 2002), i.e., environmental variables such as light, temperature, and rainfall determines the litterfall variation among the species within the forests (Bray and Gorham 1964; Qiulu et al. 1998; Zhang et al. 2014).

Litterfall production is significantly correlated to ambient temperature and seasonal rainfall (Seta and Zerihun 2018). Rainfall has a twofold influence on litter production because it may induce shedding of senescent leaves (Liu 2012), and non-senescent leaves may also shade due to heavy rainfall at some time of the year (Scheer 2009). However, in contrary to this, Zhang et al. (2014) reported that litterfall production in the wet season is less compared to the dry seasons in tropical forest ecosystem. Several authors (Sundarapandian and Swamy 1999; Qiulu et al. 1998; Liu 2012; Giebelmann et al. 2013) have also reported that peak litterfall mass was recorded in autumn, summer, and spring compared to winter). The significant positive relationship between climate variable and season suggests that the changes in climate and season may result in significant changes in reproductive allocation. All these studies showed that although the litter production in tropical forest ecosystem varies according to age and habitat of tree species, it is highly determined by seasonal and local climate condition.

Species diversity

According to Taylor et al. (1989), 10–30% of the net primary production (NPP) enters the aboveground litter layer, and fine litterfall, such as roots, reproductive parts, and leaves, also enters tropical forest soils. Accordingly, the total input from dead plant dry mass, which enters soil, is estimated to be 12 tons ha^{-1} $year^{-1}$. However, because various forest ecosystems are composed of a variety of different tree species, all of them are contributing to the annual litter input differently, which in turn has a strong impact on the overall litter production and litter pool (Taylor et al. 1989; Gonzalez et al. 2005).

Structural pattern of vegetation

The strong presence or dominance of some species through a selection effect positively relates to the basal area of the tree strata, which positively correlates with litter productivity (Ruiz-Benito et al. 2014). Dominant species, which have larger basal area and volume, may exhibit marked leaf loss throughout the year and enhance nutrient addition to the soil (Ruiz-Benito et al. 2014). The differences in basal area, volume, and dominance among species have a direct influence on litter production (Ruiz-Benito et al. 2014). For example, Ruiz-Benito et al. (2014) showed that in some tree species, basal area, volume, and dominance have showed a positive relationship in the upper stratum but a negative relationship in the lower stratum.

Age, density, and basal area of trees

Vivanco and Austin (2008) have reported that litter production of *Tectona grandis* increased with an increase in age. On contrary, Bray and Gorham (1964) found that litterfall has linear relationship with age alone because once the tree canopy becomes closed, litter production could decrease. Some authors (Chaubey et al. 1988; Mishra et al. 2004) have showed that although the tree age did not affect litterfall production independently, age, density, and basal area, all in combinations, could play a great role in litter production.

Factors affecting the rate of litter decomposition in forest ecosystems

There are three major processes through which decomposition occurs (Perez-Harguindeguy et al. 2000; Hattenschwiler and Jorgensen 2010; Giebelmann et al. 2013): (1) fragmentation of litter into smaller sizes, (2) leaching of soluble compounds into soil, and (3) catabolism by decomposer organisms. According to Swift et al. (1979), the main factors, which influence the litter decomposition, are the following: the litter quality, the physical-chemical environment, and the decomposer organisms; and the details on these factors are discussed below.

Litter quality

The physical quality and chemical composition of leaves vary tremendously among plant species (Perez-Harguindeguy et al. 2000) and have a major influence on the properties and functioning of forest ecosystems (Giebelmann et al. 2013; Parson et al. 2014), i.e., the proper functioning of forest ecosystem is usually explained by the biochemical and physical quality of leaf litter (Prescott 2005; Sariyildiz 2008; Hattenschwiler and Jorgensen 2010). The difference in the life span of leaf could contribute to the variation in leaf quality. Leaves with a long life span have low specific leaf area (often related to leaf toughness) and nutrient concentration (Perez-Harguindeguy et al. 2000; Chapman and Koch 2007). On the other hand, leaves with long life span have a large amount of lignin and tannin (Szanser et al. 2001; Giebelmann et al. 2013). Moreover, intra- and interdifferences of plant litter have a great impact on the nitrogen inputs and loses (Wedin et al. 1995; Seta and Zerihun 2018).

Within a forest ecosystem, inter- and intraspecific variation in leaf litter quality has substantial effect on the rate of leaf litter decay and mineralization (Scheer 2009; Giebelmann et al. 2013). The litter quality difference among the species might be explained by the difference in the amount of nutrients and different compounds and their ratio and the genotypic variations among species (Rawat and Nautiyal 2009; Wedin et al. 1995). However, the difference in litter quality within species may largely reflect the phenotypic variation, in which it is emanated from the environmental factors and/or biotic interaction across wider environment (Berg and Laskowski 2006).

Litter containing high amount of lignin decomposes slower than litter containing high amount of starch (Berg and Laskowskil 2006). Litter is high in content of cellulose and lignin, needs special microorganisms, and is difficult to be degraded, for example, oak litter (Giebelmann et al. 2013). The rate of litter decomposition is negatively correlated with C/N and lignin/N ratio of the initial litter, while it is positively correlated with N content of the initial litter (Berg and Laskowski 2006). Litters with lower C/N ratios decompose faster than litters with higher C/N ratio (Swift et al. 1979), i.e., due to the growth of soil microbes, litters with high N concentrations decompose faster than litters with low N concentrations (Mctiernan et al. 1997; Berg and Laskowski 2006).

The decomposition of plant material will be enhanced if the C:N is less than 20, whereas when the C:N is greater than 20, the decomposition will be slower (Swift et al. 1979). Therefore, during the decomposition of plant residues, the relative availability of C and N in litter to the microbial population determines the carbon and nutrient dynamics (Cadish and Giller 1997). In summary, the spatial and temporal variation in litter quality is very important for nutrient cycling, in general, and for decomposition processes (Chapman and Koch 2007). However, considering only some chemical parameters, especially at the early stage of decomposition, do not guarantee the decomposability of the leaf litter (Prescott 2005; Vivanco and Austin 2008).

Environment, climate factors, and soil property

As Table 4 shows, further to the chemical component of the soil, the physical structure, which indirectly controls the temperature and humidity, affect the leaf litter decomposition in the soil (Taylor et al. 1989; Aravena et al. 2002; Rawat and Nautiyal 2009). For example, the degree of litter decomposition is highly influenced by the organic forest top soil due to the higher microbial decomposer communities and the microclimatic conditions that favor stand-specific litter decomposition (Hayes and Holl 2003); Moreover, soil pH, temperature, and NH_4^-–N concentration have a great influence on the rate of litter decomposition.

Litter decomposition rate could also be affected by temperature, moisture, and other microclimate factors. In agreement with this, several authors (Pant and Tiwari 1992; Devis and Yadav 2007; Tripathi et al. 2009) have reported that the rate of litter decomposition was slow in winter and fast during rainy season, and the major reasons for the higher litter decomposition rate in rainy season could be the presence of sufficient rainfall, suitable moisture, and higher micro-fungal populations. Pant and Tiwari (1992) and Kumar et al. (2010) also concluded that there is a high rate of litter decomposition and an increase in weight loss in rainy seasons due to high rainfall, soil moisture, and microbial load. However, despite this being an obvious statement, it is still debated on which climatic index best predicts decay rates. For example, Meentemeyer (1978) concluded that as there is water available in soil, actual evapotranspiration is the major factor, which predicts the rate of litter decomposition. On the contrary, many authors (Gillon

Table 4 Role of soil physical and chemical properties, other environmental factors, and anthropogenic activities on litter decomposition process

Soil property	Role in litter decomposition
• Texture	• Stimulate water and nutrient dynamics, porosity, permeability, and surface area (Krishna and Mohan 2007).
• pH	• In flooded area, biochemical decomposition may be limited by low pH and low oxygen concentration (Cuevas and Medina 1986).
• Organic matter	• Because organic matter affects the different physico-chemical factors such as pH and bulk density, it has a big role in litter decomposition (Cuevas and Medina 1986). • Because organic matter can increase the population of soil organisms, it plays a significant role in litter mixing and decomposition (Akpor et al. 2006).
• Soil nutrients	• Because soil nutrients (e.g., N and P) regulate the microbial activities in the soil, it has a direct effect on litter decomposition (Akpor et al. 2006; Devis and Yadava 2007). • Soil nutrient availability influences the decomposition of leaf litter: (a) through altering the microclimate, where litter decomposition occurs, and (b) through regulating the way in which the leaf litter enters the ecosystem (Gartner and Cardon 2006).
• Ecosystems	• Decomposition varies among ecosystem (faster rates are found in tropical forests compared to temperate forests (Devis and Yadava 2007
• Temperature and water regimes	• For example, since there is a lack of water in desert areas, it limits microbial activities, and decomposition is almost negligible (Perez-Suarez et al. 2012).
• Season	• Litter decomposition may vary within various seasons (Cuevas and Lugo 1998).
• Anthropogenic activities	• Compared to litter remaining on the soil surface, litter incorporated into the soil decomposes faster (Cuevas and Lugo 1998).

et al. 1993; Joffre et al. 2001; Magid et al. 2002) strongly disagree with this concept, and they argue that the relationship between actual evapotranspiration and litter decomposition does not provide reliable indicators of decay rates.

Furthermore, compared to any other plant cover microclimate, litter decomposes faster than the site of its origin (Chapman and Koch 2007). For example, broadleaved trees decompose faster in broadleaved habitat than in conifer habitat (Aravena et al. 2002; Rawat and Nautiyal 2009). Depending on the species of vegetation, litter decomposes faster at lower elevation compared to higher altitudes (Veen et al. 2015). Furthermore, litter decomposition rate decreased with soil N content, soil C:N and C:P ratio, soil organic matter content, and fungal:bacterial ratio (Parsons et al. 2014; Veen et al. 2015).

Decomposer communities in soil

The decomposer communities in the soil are extremely diverse and have different functional capabilities (Schinner 1996; Crawford 1988). As Table 5 shows, the soil fauna plays great roles in conditioning the litter and stimulating microbial action, whereas soil microbes are the main drivers of the decomposition processes (Coleman and Crossley 1996). The major soil fauna and microbes that are associated with litter decomposition include algae, actinomycetes, bacteria, and fungi (McCarthy 1987; Schaefer and Schauermann 1990), and the arrangement and abundance of these soil fauna and microbial communities affect the rate of litter decomposition (McCarthy 1987; Crawford 1988).

The rate of litter decomposition, nutrient mineralization, and soil fertility is directly related to the functional role and metabolic activities of the decomposer communities (Swift et al. 1979; McCarthy 1987). Furthermore, the litter decomposition processes such as the physical breakdown of litter, the transfer of organic matter to nutrients, and the release of carbon dioxide to the atmosphere are highly affected by the composition of the decomposer communities (Schinner 1996; McCarthy 1987; Dilly et al. 2004). Even though their role and mechanisms in the litter decomposition process are different (Table 5), fungi and bacteria the major engines in the litter decomposition processes (Swift et al. 1979; McCarthy 1987). For example, fungi can colonize freshly fallen litter and to transfer N and C between the litter layers through colonizing the freshly fallen leaves; however, bacteria depends on the flow of substrate into their cells (Vivanco and Austin 2008; Laganiere et al. 2010).

Some decomposers have special relationship with some plant species and are specialized to breakdown the litter of these species (Brown 1995; Vivanco and Austin 2008). Since the decomposer food web, consisting of fauna and microbial communities, varies in the underneath of different forest floors, it affects the rates at which various litter fractions are mineralized (Laganiere et al. 2010). The amount and activity of decomposers and the quality of the substrates determine the decomposition rate of leaf litter (Akpor et al. 2006; Giebelmann et al. 2013; Pérez-Suárez et al. 2009).

Table 5 Summary of the roles of soil fauna and microbes in litter decomposition process

	Roles	References
Soil fauna	• Mix the mineral soil and soil organic matter and change the water infiltration and water regime	Brown 1995; Lavelle et al. 1997)
	• Alter the soil physical, chemical, and biological activities through tillering	Gonzalez et al. 2001; Gonzalez and Zou 1999
	• Increase the surface area of substrate for microbial use	Gonzalez et al. 2001; Gonzalez and Zou 1999
	• Stimulate the microbial population which are involved the decomposition process	Gonzalez et al. 2001; Gonzalez and Zou 1999
	• Releases soil enzymes, which can help to process root-driven carbon, small organic matter, and fresh above-ground litter, as energy source for bacteria (for example, fungi)	Schinner 1996; Gonzalez and Zou 1999
	• Synthesize cellulose and lignin-degrading enzymes (for example, actinomycetes)	McCarthy 1987; Crawford 1988
	• Microalgae fix nitrogen and produce organic matter via photosynthesis.	Crawford 1988; Gonzalez and Zou 1999
	• Augment the nutrient in soil by adding nitrogenous compounds present in their excreta and dead tissue	Gonzalez and Zou 1999; Gonzalez et al. 2001
Soil microbes	• Release soil enzymes for the purpose of breaking the larger compounds	Vivanco and Austin 2008; Brady and Weil 2010;
	• Decompose the fragmented litter and release nutrients	Laganiere et al. 2010

Plant species composition and diversity

The rate of decomposition of one species might be affected by neighboring species (Melo et al. 2013). Compared to monoculture, mixed species decompose faster, which indicate the weaker positive non-additive effect in mixtures. This also implies that in some monoculture species, the strongly lignified leaf tissue of monoculture species could hamper further decomposition of leaf litter due to the high structural stability (Cadish and Giller 1997; Mishra et al. 2004). The diversity of microbial communities involved in decomposition processes increases as the tree species richness increases, which in turn increases the rate of leaf decomposition (Chapman and Koch 2007). When nutrient concentration differs among species, the litters in forests with high tree diversity decompose rapidly (Chaubey et al. 1988; Clark et al. 2001).

The litter mixing effect on the decomposition rate is greatly influenced by the litter quality based on species composition (Hattenschwiler and Jorgensen 2010). The decomposition of an individual type of litter could be altered by a litter mixture; however, litter mixture has a synergetic effect on leaf litter with similar structure, but not on litter mixture with distinct leaf texture (Seta and Zerihun 2018). Mixing litter could have additive or non-additive (synergism or antagonism) effects on litter decomposition than monocultures (for example, Gartner and Cardon 2004; Hattenschwiler and Jorgensen 2010). The decomposition of recalcitrant litters in the mixture decomposes faster, due to the transferring of litter from high-quality to low-quality litter, which in turn favors the colonization of micronutrients (Mctiernan et al. 1997).

Conclusions

Litter production and its decomposition processes are highly important and have a significant role in the nutrient and biogeochemical cycles and healthy functioning of tropical forest ecosystem. Moreover, it is very important to understand the various factors that influence litter decomposition for a broader understanding of ecosystem functioning. However, since the litter production and its decomposition is a complex process, our knowledge about the various natural and anthropogenic factors, which influence the litter production and its decomposition process, is very weak, and general conclusions are still difficult to draw. It is also very important to study the litter production and its decomposition processes in the context of the increasing impacts of various natural and anthropogenic factors on the nutrient and biogeochemical cycle of tropical forest ecosystem.

Abbreviations

CO_2: Carbon dioxide; ET: Evapotranspiration; SFM: Sustainable forest management; SOC: Soil organic carbon; SOM: Soil organic matter

Acknowledgements

The author thanks Mrs. Firehiowt Tariku for her valuable comments on the review paper.

Authors' contributions

The author gathered, organized, and processed the information and wrote the manuscript. The author read and approved the final manuscript.

Funding

The Ethiopian Environment and Forest Research Institute cover the salary of the author, while I prepared this review paper.

Availability of data and materials

The materials and data used in this paper are available from the corresponding author on request.

Ethics approval and consent to participate

This research was performed in accordance with the laws, guidelines, and ethical standards of Ethiopia where the review was performed.

Consent for publication

Not applicable

Competing interests

The author declares that he has no competing interests.

Received: 17 July 2019 Accepted: 19 January 2020
Published online: 07 May 2020

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