Litter decomposition as an Ecosystem service

U.M. Chandrashekara
Kerala Forest Research Institute Sub Centre, Nilambur

1. Introduction

In a broad sense, ecosystem services refer to the range of conditions and processes through which natural ecosystems, and the species that they contain, help sustain and fulfil human life (Daily, 1997). With a significant share of the world's remaining natural capital, the economies of developing countries are heavily reliant on natural resources and hence ecosystem services support life which include production of ecosystem goods and also following functions (Erlich and Erlich, 1980).

- purification of air and water
- mitigation of droughts and floods
- generation and preservation of soils and renewal of their fertility
- detoxification and decomposition of wastes
- pollination of crops and natural vegetation
- dispersal of seeds
- cycling and movement of nutrients
- control of the vast majority of potential agricultural pests
- maintenance of biodiversity
- protection of coastal shores from erosion by waves
- protection from the sun's harmful ultraviolet rays
- partial stabilization of climate
- moderation of weather extremes and their impacts
- provision of aesthetic beauty and intellectual stimulation that lift the human spirit

Importance of ecosystem services is clearer in the rural landscapes of the developing countries as a large proportion of the poor depends on ecosystem services for survival. It is estimated that of the 1.2 billion people living in extreme poverty, approximately 900 million live in rural areas, where biodiversity and ecosystem contribute to food security and nutrition, providing the raw materials that underpin health system (both formal and informal) (Wetlands International, 2005). For instance, in the Wayanad Wildlife Sanctuary, tribal communities mainly depend on non-wood forest products (NWFP) for their survival. It is estimated that the economic value of biomass of 11 NWFP species heavily harvested by tribal alone is about Rs. 49,32,633 (Chandrashekara et al., 2000). Furthermore, there are a number of reasons to indicate the relevance of ecosystem services to the rural community of the developing countries. For instance, for many rural Indian families, agriculture (often subsistence) is the main occupation and these families have limited access to alternative sources of income. Agricultural activities mean exposure to risks from pest outbreak, flood and water scarcity. In addition, the rural poor are more likely to inhabit marginal, less agriculturally productive land, where harvest is more vulnerable to deterioration in soil and water quality. It may also be pointed here that even the economic growth alone may not be sufficient to reduce pressures on the environment. For instance in Nilgiri Biosphere Reserve (NBR), farmers who are somewhat better off make more use of ecosystem good and services in absolute terms (eg. as income grows so does application of green leaf manure).

Among different ecosystems services of terrestrial ecosystems such as natural forests, litter decomposition is a critical service that removes wastes, recycles nutrients, and renews soil fertility and carbon sequestration (Wall and Virginia, 2000). During the process of decomposition, dead organic matters convert into smaller and simpler compounds. The products of complete decomposition are carbon dioxide, water, and inorganic ions (like ammonium, nitrate, phosphate, and sulphate). In fact, the importance of litter decomposition as an ecological service that supports other ecosystem services is already recognized. For instance, biomass production, nutrient cycling and biodiversity conservation are a few among other ecological services for which the litter decomposition plays a central role. It may also be pointed out here that the forest ecologists have paid considerable attention to litter decomposition in relation to nutrient cycling and soil productivity. The obvious reason is that litter decay has a pronounced effect on the availability of nutrients, and nutrient availability is the basic determinant of biodiversity, plant growth and productivity.

Litter decomposition is mainly a biological process carried out by insects, worms, bacteria, and fungi, both on soil surface and in the soil. However, apart from soil micro- and macro faunal activity there are three more factors affecting litter decomposition. They include a) climatic factors, b) substrate and its quality, c) type of vegetation, and d) vegetation cover. In the present paper, the factors influencing litter decomposition, rate of litter decomposition and nutrient pattern are discussed.

In agroforestry systems of Kerala, green leaf manure is used as mulch. Green leaves of different forest tree species and shrubs will be incorporated either separately or in mixture. Since the soil physical and chemical properties may be different in different agroforestry systems, litter decay rate and nutrient release pattern of different mulch species may be different. In addition, even in a given type of agroforestry system, a wide variation can be seen in terms of soil physical and chemical properties and aboveground vegetation. In this context, in the present paper, available information on litter decomposition are reviewed with a main objective to develop approaches to study the litter decomposition and nutrient release pattern of different mulch species.

2. Methods to study litter decomposition

Leaf litter decomposition is most commonly measured using the litter bag technique. A known quantity of leaf litter is placed into a mesh bag which is then inserted into the litter layer of a forest floor. Bags are harvested at periodic intervals, dried and reweighed to determine the amount of mass lost. By incubating the leaves in situ, they are exposed to the normal fluctuations in temperature and moisture. The litter bag technique has both advantages and disadvantages (Lousier and Parkinson, 1975, Woods and Raison, 1982). The advantage of this technique is it allows registering the litter weight loss in filed and the subsequent chemical and biological examination of the material involved (Weber, 1987). Typically, 1-2 mm mesh size and 10 x10cm to 30 x30 cm nylon bags or fibre glass screen or polyvinyl bags with 5-20 g (dry weight) samples are used (Anderson and Ingram, 1993). However, the mesh-size may hinder soil faunal activities. In this context, improved methods for litter decomposition studies need to be developed.

The decomposition rate constant, k, can be calculated from the decay curve using the following equation

$$\mathrm{Ln}\ (M_0/M_t) = k * t$$

where M_0 = mass of litter at time 0, M_t = mass of litter at time t, t= time of incubation, and k = decomposition rate constant.

Half lives ($t_{0.5}$) of decomposing litter samples are estimated from the values as follows:

$$t_{0.5} = 0.693/k$$

Similarly, time taken for 95% decay can be estimated as follows

$$t_{0.95} = 2.9957/k$$

According to McClaugherty and Berg (1987) the single exponential model described above may be suitable for homogeneous substrate, and the materials with high nutritional status especially nitrogen and less of complex organic constituents such as lignin and tannins. However, double exponential model (Bunnell and Tait, 1974) may be suitable for analyzing the decompositions data obtained for heterogeneous substrate.

Rate of decomposition can also be measured by calculating the ratio of annual litterfall to the equilibrium litter on the forest floor. Generally, the equilibrium (or the steady state) litter on the plots are measured biannually in two or more successive years. The average annual litter fall measured by adopting litter bag technique. According to Anderson and Swift (1983) the litter turnover coefficient calculated by this method is suitable for comparison of humid tropical forests. The other two methods commonly used for litter decomposition studies include a) measurement of carbon dioxide evolution or oxygen uptake (Reiners, 1968), and b) determination of the microbial biomass in the litter layer.

As already indicated in the agroforestry systems of Kerala, green leaf manure consisting of leaves of single species or a mixture of species is incorporated. Thus the approach to determine the rate of decomposition should involve usage of both single exponential model and double exponential model.

3. Patterns of litter decomposition and nutrient release

Generally there are two steps in the litter decomposition, each one with different decomposition rates (Swift and Anderson, 1983). Berg and Co-workers (Berg and Staaf, 1980; McClaugherty and Berg, 1987) have shown that in the initial stages (0 to 3 months) of leaf breakdown small soluble carbon molecules like starches and amino acids are lost first leaving behind the more recalcitrant molecules like lignin. Decomposition during this first phase is rapid because these molecules are easy to breakdown and energy rich. The second stage of decomposition- the beak down of lignin- is much slower because lignin consists of very large and complex molecules. This rapid initial breakdown followed by a longer period of slow decomposition results in a mass loss curve that resembles an exponential decay curve.

During the process of decomposition, amount of different nutrients in the decomposing litter generally do not relate with litter biomass. For instance, in the tropical wet evergreen forest of Nelliampathy (Chandrashekara, 1992) nitrogen and phosphorous showed much fluctuation during the 1-year period, often exceeding the initial concentration. Potassium, calcium and magnesium showed a gradual decline with passage of time. The relative increase in the concentration of nitrogen and phosphorous in the leaf litter during the process of decomposition and their rapid fluctuation may be related to immobilization of these two nutrients by phylloplane microflora., so that they are released more slowly and at the same rate as organic matter loss (Gosz et al., 1973; Toky and Ramakrishnan, 1984). In contrast, labile element like potassium is released at a faster rate. It was also recorded that in general nutrient levels at the end of one year was in the order of N>P>Mg>Ca>K. However, when different species are considered mobility of the nutrients from decomposing litter may show different order. In this context, studies related to decomposition and nutrient release patterns in green leaf manure (consisting of leaves single species or a mixture species) will have significance as the information thus generated could be useful to understand the synchronization of nutrient release by green leaf manure and the nutrient up take by crop species.

4. Factors affecting litter decomposition

The rate and patterns of litter decomposition are dependent on the interaction of climate, soil biota and quality and quantity of organic matter (Swift et al., 1979). One can predict gross estimates of decomposition based on the climate and the C:N:lignin rations organic matter (litter). The primary factors which affect litter decomposition are discussed under following heads: a) climate, b) vegetation, c) substrate and its quality and d) soil biota.

4.1. Climatic factors

Climate markedly modifies the nature and rapidity of litter decomposition. Moisture and temperature are among the most crucial variables (Brinson, 1977; Singh, 1969) because they affect both the development of plant cover and the activities of microorganisms which are highly critical factors in soil formation. Effects of soil moisture on litter decomposition are little complicated. Decomposition is inhibited in very dry soils because bacteria and fungi dry out. Decomposition is also slow in very wet soils because anaerobic conditions develop in saturated soils. Decomposition proceeds at faster rate at intermediate water contents. Kononova (1975), citing several other publications, concluded that the highest intensity of organic matter decomposition was observed when the soil moisture content of about 60-80% of its maximum water-holding capacity. According to Van der Drift (1963) moisture passing through the detritus may be important in speeding decomposition. Therefore, studies in litter decay should not be compared unless moisture regimes are the same.

Temperature is often the primary factor determining rates of litter decomposition (Meentemeyer, 1978, Anderson, 1991, Hobbie, 1996) and decomposition rate are generally more sensitive to temperature than are rates of net primary production (Lloyd and Taylor, 1994). Thus, the balance between ecosystem C fixation and decomposition may be altered under a warmer climate, potentially causing a dramatic increase in the flux of CO_2 from soils to the atmosphere (Cox et al., 2000). For each 10^0 C increase in temperature between 20 and 40^0 C the rate of CO_2 production doubled (Wiant, 1967). No CO_2 production at all was detected at 10^0 C and 50^0 C or above it declined markedly. According to Kononova (1975) the highest intensity of organic matter decomposition was observed under conditions of moderate temperature (about 30^0 C). Increase or decrease of temperature beyond the optimal levels brought about a decline in the rate of organic matter decomposition. Therefore, studies on litter decay should not be compared unless temperature regimes are the same. Differences in litter decomposition rate at various altitudes, due to variation in temperature were reported by William and Gray (1974). Shanks and Olson (1961) compared litter decay beneath natural stands at various elevations and concluded that there was an average decrease in breakdown of nearly 2% for each 1^0 C drop in mean temperature. The influence of temperature on the decomposition of lignin is especially marked. At 37^0 C, lignin decomposes rapidly, with 50-60% of it disappearing within 9 months (Waksman and Gerretsen, 1931).

Meentemeyer (1978) used annual actual evapotranspiration as the index of predictor variable of decomposition rate.

The decomposition rates in different types of forests in the Western Ghats region appear to be correlated with rainfall. According to Swamy (1989) the rate of decomposition in rainfall rich forests is faster than in those where the rainfall is comparatively less. The percolating water from rainfall may leach the excrements and remains of organisms down to the lower horizons, where other specialized microbes will attack the remaining organic matter (Van der Drift, 1963).

The litter breakdown rate varies with season. Gholz et al. (2000) and Loomis (1975) found that decomposition was rapid in summer, whereas Lang (1974) estimated the leaf litter decay to 3.75 g/m^2/day during the autumn months and 0.80 g/m^2/day during the remainder of the year. Boonyawat and Ngamponsai (1974) supported Lang's result when they found that the highest decomposition of hill evergreen forest litter occurred in the late rainy season and early winter (0.36 t /ha/month) and the lowest rate in summer (0.14 t/ha/month). Madge (1965) concluded that litter disappearance in Nigeria occurred mainly during the wet season, owing to the activity of mites and collembolan.

It may be mentioned here that agroforesters of Kerala apply for their crop trees the green leaf manure generally during September-November and leaf litter during February-April. Apart from the availability of either green leaf manure or leaf litter, probably season of their application may have certain bearing on the litter decomposition and nutrient release in relation to nutrient uptake by the crop trees, and this aspect needs to be investigated.

In the Kerala part of NBR, while some tree based farms are located in slightly elevated areas, other farms being transformed paddy fields inundate during the rainy season. Thus, a comparative study on the litter decomposition pattern in two types of farms (inundated and un-inundated) which are have same species as the dominant crop may provide information on the impact of water saturation on litter decomposition and biotic activities.

4.2. Growing Vegetation

In general, the decay rate in tropical plantations is lesser than those in natural forests (O'connell and Sankaran, 1997). One of the reasons for slow rate of decomposition is the lack of ground cover. The ground cover can provide favorable microclimate and promote the abundance and activities of soil fauna and microorganisms. However, there are reports to indicate that the presence of growing plant significantly alters decomposition dynamics and decreases the rates of decomposition (Dormaar, 1990). Living plants can decrease decomposition rate because a) microbes preferentially use labile material provided by living roots rather than more recalcitrant litter, b) roots release compounds that inhibit microbial activity, c) plants compete with microbes for uptake of nutrients and organic compounds and/ or d) exudates stimulate predation on microbes and thus decrease microbial populations. In contrast, growing plants can stimulate decomposition through inputs of labile carbon that increases the activity and turnover of microbes (Cheng and Coleman, 1990; Sallih and Bottner, 1988). Plants can also influence decomposition through their effects on soil temperature, moisture (Mack et al., 2001;Van der Krift et al., 2002) or oxygen concentration (Allen et al., 2002).

4.3. Vegetation type

The decay rate in general is faster in the tropical region than in the temperate region (Jennay et al., 1949). Even within the tropical region, leaf litter decomposition rates vary with the types of forests. For instance, in the Western Ghats of India, decay rate is faster in evergreen forest followed by semi-evergreen forest and moist deciduous forest (Swamy, 1989). Forest canopy gaps formed either by natural tree fall or branch fall or by human activities such as selective logging can also alter the process and the rate of litter decomposition (Chandrashekara, 1992). Canopy gap formation by natural means may lead to a situation where the microclimate is more favourable than that in closed canopy area for litter decomposition. Thus, litter decomposing rate increased with increase in gap size. However, the rate of litter decomposition declined as the canopy gaps are closed owing to reduction in the light and temperature. A sharp decline in litter decomposition rate due to selective logging (Chandrashekara, 1992) and clear felling (Maheswaran and Gunatilleke, 1988) when compare to that in undisturbed forests could be attributed to the desiccation of leaves and surface soil under more intense disturbance of the vegetation.

It may be mentioned here that in Nilgiri Biosphere Reserve, even in a given type of farm, a wide variation can be seen between farms in terms of canopy opening. Thus, the pattern and rate of decomposition of litter and green leaf manure may be different in different farms. In this context, there is a scope to study the relation between canopy opening and litter decomposition rate in agroforestry systems in Kerala.

4.4. Substrate and its quality

The quality of the leaves as a food source for microbial decomposers is another important factor that determines the rate and pattern of litter decomposition. Substrate quality has been defined in many different ways-as the nitrogen concentration (N), as the lignin content, and as the C:N ratio (Moorehead et al., 1996). Researchers have found that decomposition of leaf litter can be predicted by the C: N ratio (Melillo et al., 1982). Basically, high quality leaves (nutrient rich-leaves) will decompose faster than low quality leaves (nutrient –poor leaves).

Many studies have shown striking difference in decomposition rates among species (Kumar, 2005; Cornelissen and Thompson, 1997). It is also reported that the decay rate coefficients of the tropical speceis are substantially greater than those of the temperate coniferous litter (Cromack et al., 1991; O'Connel and Sankaran, 1997). Relationship between the species successional status and the rate of decomposition has been studied by Chandrashekara (1992). The decay rate coefficients of primary species (k values of 0.61, 0.8 and 1.39 yr^{-1} for *Cullenia exarillata*, *Mesua nagassarium* and *Palaquium ellipticum*) are substantially lesser than those of late secondary (k= 1.94 yr^{-1} for *Actinodaphne bourdillonii*) and early secondary species ((k=3.21and 2.95 yr^{-1} respectively for *Clerodendron infortunatum* and *Macaranga peltata*). The slower rate of decomposition of Cullenia exarillata- a primary species may partly be related to its hard and leathery leaves. In this species, leaves are comparatively nitrogen rich, but still decompose relatively slowly. This observation is different from what others have implicated with nitrogen status of the litter (Singh and Gupta, 1977, Tanner, 1981). The differential rate of decomposing of early secondary and primary species may confer an advantage to the former in terms of a faster turnover rate of nutrients which is important for these exploitative early secondary species (Boojh and Ramakrishnan, 1982), but help in conserving nutrients of primary species through gradual release (La Caro and Rudd, 1985) so that the primary species with conservation strategy are able to utilize relatively slowly during their slow growth phase.

Generally speaking, the rate of decomposition is highest in species with maximum ash and nitrogen contents and minimal C: N ratios and lignin contents (Singh 1969). Broadfoot and Pierre (1939) found a highly significant correlation between litter decomposition and each of five independent variables: excess base, water-soluble organic matter, total nitrogen, total ash and total calcium. The multiple coefficients of correlation between percent decomposition and the three variables- total nitrogen, water-soluble organic matter, and excess base was found to be 0.86. Kucera (1959) also reported a positive correlation between both rapidity of decay and high ash content of hot water soluble materials. Since the chemical composition of litter affects its rate of decomposition, it is assumed also to have great significance in determining the release of nutrients.

4.5. Soil biota

Soil biota, primarily at a functional group level, is known to regulate ecosystem processes such as decomposition, carbon sequestration and nutrient cycling (Paustian et al., 2000). Soil biota, playing a meditative role, in decomposition may affect the type and availability of nutrients and thus community interactions. For example, Binkley and Christian (1998) state "the black box of the soil community can strongly affect the supply of nutrients --- a black box--- clearly needs to be taken apart and examined in greater detail". Evidence from the 1980's on deserts (Whitford et al., 1982) and from sub alpine and wet and dry tropical ecosystems (Gonzalez and Seastedt, 2001) again indicate that soil fauna are key to litter decomposition. It is also reported that the seasonal variation in rate of decomposition could be variation in abundance of soil fauna. For instance, Madge (1965) concluded that since more animals are there on the litter layer during the wet season than in dry season, rate of decomposition was faster in the former season. When animals were completely excluded for nine months, no visible breakdown of oak and beech leaf litter occurred (Edwards and Heath, 1963). The same investigators reported that in earthworms removed litter the decomposition rate is three times faster than the litter from where smaller invertebrates such as springtails, enchytraeids and dipterous larvae were removed. A common carbomate insecticide (carbofuran), when applied at recommended dosage, reduced the decomposition rate of red maple to between 0.99 and 1.26 gm m^{-2} day^{-1}, This is chiefly because such insecticides have been found to be highly toxic to earthworm (Weary and Merriam, 1978). Similarly Heneghan et al., (1999) and Gonzalez and Seastedt (2001) found that excluding micro invertebrates slowed decomposition rate of leaf liter in humid tropical forests.

5. Conclusions

Decomposition is a critical process for regulating nutrient cycling and production in all ecosystems. Though attempts are being made to assign economic value for some of the ecosystem services such as biomass production, aesthetic beauty of natural forests, pollination of crops and natural vegetation etc., such an attempt has not been made in the case of litter decomposition and associated ecosystem services. In fact, litter decomposition is one among several other ecosystem services which are not traded in markets and hence do not have prices, and thus are interpreted as having no value when it comes to making decision about their use. In this context, quantities evidence on economic value of litter decomposition needs to be generated. As a prerequisite, methods for analyzing the ecological economics of litter decompositions are need to be developed.

There is an array of variables such as temperature, moisture, soil physical and chemical properties, soil biota, vegetation type and composition, substrate quality etc. which control the litter decomposition. In the agroforestry systems of Kerala, green leaf manure application to crop lands is a common practice for improving soil fertility and crop yield. However, studies on influence of different above mentioned variables on the rate of litter decomposition and nutrient release are lacking. In this context, approaches to litter decomposition studies may be to evaluate

a) the rate of decomposition of green leaf manure, comprising single species and/or a mixture of species by using single exponential and double exponential models,
b) pattern of nutrient release in green leaf manure, comprising of single species and/or a mixture of species and understand the synchrony between nutrient release by manure and nutrient uptake by crops,
c) litter decomposition rates in a given type of crop land (eg. homegardens) but transformed from different landuse systems (eg. forest, paddy field etc.),
d) the relationship between quantity of light available and litter decomposition rate in a given type of landuse systems,
e) substrate quality in terms of carbon, nitrogen and lignin content in different green leaf manure species and their impact on litter decomposition rate, and

f) variation in the abundance of different soil faun in the litter bag during the process of decomposition of different green leaf manure species

6. References

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