Leaf-litter decomposition and nutrient dynamics of five selected tropical tree species

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Leaf-litter decomposition in terrestrial ecosystems has a major role in recycling the nutrients to the soil. Nutrient dynamics is the way nutrients cycle in an ecosystem. The present study was conducted for five selected tropical tree species viz. Shorea robusta, Ficus hookeri, Mallotus philippensis, Artocarpus lakoocha and Dillenia pentagyna at Hetauda, Makawanpur. This paper aims to determine the litter decomposition rate-constant and nutrient mineralization pattern of the selected species. The litter-bag method was used to assess the decomposition and nutrient dynamics for one year. Both decomposition rate-constant and weight loss were highest for M. philippensis (% weight loss = 73.49; k = 0.33) and lowest for S. robusta (% weight loss = 54.01; k = 0.18). In general, weight remaining showed a strong negative correlation with N and P concentration but a slightly negative with K. However, the remaining weight of litter showed a strong positive correlation with C : N ratio, thus indicating a good predictor of mass loss and mineralization. The study showed that there was no net release of nitrogen during the one-year study period; however, the net P release was found to be highest for S. robusta followed by D. pentagyna and the net K release was highest in F. hookeri followed by A. lakoocha.

Keywords: Immobilization, leaf-litter decomposition, nutrient dynamics, weight remaining

The dead plant materials such as leaves, bark, needles, and twigs that have fallen on the ground are called litter. As the majority of organic matter (OM) produced by plants is returned to the soil as litter, the transfer of nutrients and energy from living biological components to the soil is the important mechanism of nutrient recycling. In the cycling of such nutrients, decomposition processes have a crucial role by releasing a complex organic compounds into simple inorganic forms takes place is called decomposition (Saha et al., 2016). The process of decomposition is primarily carried out by bacteria and fungi, thus the rate of decomposition entirely depends on microbial activities which in turn, get affected by soil character and climatic condition in an area (Berg and McClouderty, 2014). Moreover, Gautam and Mandal (2016) have also reported the effect of disturbance on litter dynamics in a moist tropical forest. Litter mass loss or decay is the sum of carbon dioxide release and discharge of compounds that contains both carbon compounds and nutrients (Brady and Weil, 2010). In general, three major factors viz. site environmental condition (particularly climate), litter quality and soil biota play a crucial role on decomposition of Leaf-litter; however, climate is known to be the dominant factor followed by litter quality influencing the decomposition process (Austin et al., 2016).
and Vitousek, 2000; Berg and McLaugherty, 2014).

Nutrient dynamics is broadly defined as the way nutrients are taken up, retained, transferred, and cycled over time and distance, in an ecosystem (Hauer and Lamberti, 2006; Allan and Castillo, 2007). Decomposition process plays an important role in maintaining soil fertility in terms of nutrient cycling and formation of soil OM (Usman et al., 2000; Singh et al., 2007; Guendehou et al., 2014). Slow decomposition rates result in the building up of OM and nutrient stocks in soil; however, fast decomposition rates help to meet plant intake requirements (Isaac and Nair, 2005). Litter diversity also influences the activity of soil communities and processes during decomposition (Chapman and Koch, 2007). Moreover, some chemical characteristics of the litter materials like lignin, polyphenol, cellulose, and hemicellulose along with C : N ratio affect decomposition (Silveira et al., 2011). A litter with higher initial N concentration usually shows a higher mass loss; however, the importance of initial N concentration decreased with time (Ross et al., 2002).

In the traditional mountain farming system of Nepal, there exists a triangular relationship among forest, agriculture, and livestock. In this system, forest trees are responsible to provide nutrient to the soil surface in the form of leaf-litter in both forest and agricultural lands. As a result, the tradition of harvesting leaf-litters from the forests for agricultural use has been a complementary practice of agriculture in rural Nepal. Leaf-litters have been used for livestock bedding and farmyard manure (FYM) production. Thus, decomposed leaf-litters become a major source of plant nutrients to the agricultural field as manure. However, most of the farmers do not know the chemical nature of the leaf-litters and their decomposition mechanism as some of the species are with complex structural biomolecules that do not provide nutrients easily. Therefore, the present study was carried out to compare the leaf-litter decomposition and nutrient dynamics of frequently used species in the study area.

**Materials and methods**

**Study area**

The study was carried out in tropical lowland (about 450 m altitude) of Makawanpur district, central Nepal. *Shorea robusta, Terminalia chebula, T. bellirica, Mallotus philippensis, Ficus spp., Adina cordifolia, Acacia catechu* and *Dalbergia sissoo* were the common species found in the study area. The experiment was set up in tropical climatic conditions having the average temperature of 29.18°C and 173.64 mm rainfall during the study period. The temperature and rainfall variations in the study area are shown in Figure 1.

![Figure 1: Monthly variation of rainfall, temperature (maximum and minimum) of the study area](source: Department of Hydrology and Meteorology, 2019)

**Selection of species**

A total of five tree species viz. *S. robusta, F. hookeri, M. philippensis, A. lakoocha* and *D. pentagyna* were selected for the study based on the key informant interview with the local farmers focusing on their use-values. Of them, *S. robusta, M. philippensis* and *D. pentagyna* were found to be highly used for animal bedding and composting whereas *F. hookeri* and *A. lakoocha* were used for fodder and composting.

**Methods**

The decomposition of the Leaf-litter of the selected tree species was studied in the open land using a nylon bag technique following Gilbert and Bocock (1960). The newly fallen leaves of the selected five species were collected from the forest-floor during the peak litter fall period (March). The litter samples were identified based on the morphological characters, and oven-dried at 70°C to a constant weight in the laboratory. For each species, 36 litter bags were prepared enclosing a 50g sample of the oven-dried leaves
into a 25×25 cm sized 2 mm thick nylon mesh which was small enough to prevent the major losses of the litter sample yet large enough to permit microbial activity, and placed at the open area during March, 2018. The litter-bags were placed separately in an open field in such manner that they were in contact with soil, and care was taken not to disturb the floor vegetation. Three litter bags of each species were recovered randomly at monthly interval from March, 2018 to March, 2019. Afterward, the samples were made free from dust and other unnecessary materials, and oven-dried at 70°C and weighted. Then, the samples were immediately brought to the Soil Laboratory at Hetauda for nutrient analysis. The nitrogen (N) content was estimated using the Micro-Kjeldahl Method whereas the phosphorus (P) and potassium (K) were determined by adopting the Spectrophotometry Method and Flame Photometer Method, respectively as per Jackson (1967). The climatic data (temperature and rainfall) obtained from the Department of Hydrology and Meteorology were used.

**Data analysis**

The decomposition rate-constant was calculated using the exponential decay model of Olsen (1963) which is expressed as - X/X_o = e^{-kt},

where, X is the dry weight remaining at time t (year), X_o is the original dry weight of the litter, and k is the decay rate coefficient.

The time required for half-life (t_{50}) was calculated as - t_{50} = 0.693/k

Likewise, correlation analysis was used to examine the relationship of the remaining weight with the remaining OM, N, P and K.

**Results and discussion**

**Initial chemical composition**

The initial nutrient composition of Leaf-litter showed variation among the selected tree species (Table 1). The highest nitrogen concentration was estimated in *A. lakoocha* (0.07%) followed by *F. hookeri* and *M. philippensis* (0.062%) and so on. The maximum phosphorus was in *D. pentagyna* (0.145%) followed by *F. hookeri* (0.131%). and least in *M. philippensis* (0.078%). Similarly, potassium was highest in *F. hookeri* (21.159%) followed by *S. robusta* (5.62%).

**Weight loss pattern**

At the end of the study, the maximum weight loss (73.49%) was observed in *M. philippensis* whereas this value was minimum (54.01%) in *S. robusta*. Likewise, the annual decomposition constant (k) values for the different species ranged from 0.18 (*S. robusta*) to 0.33 (*M. philippensis*) and the half-lives (t_{50}) from 3.85 to 2.1, respectively (see Table 2). Comparatively, the rates of decomposition of the leaf-litters of *F. hookeri, M. philippensis, A. lakoocha* and *D. pentagyna* were found to be higher at the end of the first month followed by a gradual mass loss for the subsequent days. However, the rate of decomposition of *S. robusta* was not higher during the first months as found in the other species; rather the rate was higher at the end of the second month (Figure 2).

**Table 1: Initial chemical composition and decomposition constant of Leaf-litter**

| Species                  | Local name | OM | N   | P   | K   | C:N  |
|--------------------------|------------|----|-----|-----|-----|------|
| *Shorea robusta* Gaertn. | Sal        | 6.19 | 0.042 | 0.116 | 5.620 | 147.376 |
| *Ficus hookeri* Miq.    | Nimaro     | 7.28 | 0.062 | 0.131 | 21.159 | 118.0654 |
| *Mallotus philippensis* (Lam.) Mull. Arg. | Sindure | 6.54 | 0.062 | 0.071 | 2.382 | 106.189 |
| *Artocarpus lakoocha* Wall. ex Roxb. | Badahar | 6.32 | 0.070 | 0.078 | 5.295 | 90.26995 |
| *Dillenia pentagyna* Roxb. | Tatari    | 6.86 | 0.048 | 0.145 | 2.429 | 143.9757 |

(Note: OM - Organic matter; N - Nitrogen, P- Phosphorus, K- Potassium, C - Carbon, k - Decomposition rate-constant)
Table 2: Annual weight loss, decomposition constant (k), half-life (t_{50}) and C: N ratio

| S. N. | Species                        | Dry mass | Weight loss (%) | Initial C:N | Final C:N |
|-------|--------------------------------|----------|-----------------|-------------|-----------|
|       |                                | k        |                 | t_{50}      |           |
| 1.    | *S. robusta* Gaertn.           | 0.18     | 54.01           | 3.85        | 147.376   | 69.94018 |
| 2.    | *F. hookeri* Miq.             | 0.24     | 65.58           | 2.89        | 118.0654  | 70.48909 |
| 3.    | *M. philippensis* (Lam.) Mull. Arg. | 0.33     | 73.49           | 2.1         | 106.189   | 60.71628 |
| 4.    | *A. lakoocha* Wall. ex Roxb.  | 0.29     | 70.53           | 2.39        | 90.26995  | 54.23127 |
| 5.    | *D. pentagyna* Roxb.          | 0.25     | 70.6            | 2.77        | 143.9757  | 62.31835 |

Changes in nutrient concentration in decomposing litter

In general, there was a significant positive correlation (except *F. hookeri*) between the remaining weight and the C: N ratio (Table 3). Kim (2007) also concluded that the lower C : N ratio increased the rate of decomposition.

Table 3. Correlation between the remaining weight and the OM, N, P & K

| Species        | Value (p) | OM | N | P | K | C:N |
|----------------|-----------|----|---|---|---|-----|
| *S. robusta*   | p 0.04    | 0.000 | 0.482 | 0.194 | 0.000 |
|                | r 0.58    | -0.945 | -0.214 | -0.385 | 0.885 |
| *F. hookeri*   | p 0.27    | 0.302 | 0.315 | 0.915 | 0.216 |
|                | r 0.33    | -0.311 | -0.303 | -0.033 | 0.368 |
| *M. philippensis* | p 0.42 | 0.005 | 0.901 | 0.021 | 0.019 |
|                | r 0.25    | -0.728 | -0.039 | -0.632 | 0.637 |
| *A. lakoocha*  | p 0.49    | 0.003 | 0.831 | 1.000 | 0.002 |
|                | r 0.21    | -0.756 | -0.066 | 0.000 | 0.773 |
| *D. pentagyna* | p 0.92    | 0.001 | 0.231 | 0.168 | 0.048 |
|                | r -0.03   | -0.809 | 0.357 | -0.407 | 0.556 |

Organic matter concentration

The percentage of the OM showed a positive correlation with the remaining weight in all the species except *D. pentagyna* which showed a slightly negative correlation (Figure 3a). However, there was no significant relationship (p>0.05) between the remaining weight and the OM except in the case of *S. robusta*. The value of the remaining OM at monthly intervals showed high fluctuation for *F. hookeri* followed by *M. philippensis*.
Nitrogen concentration

The initial N concentration of *A. lakoocha* (0.07%), was found to be the highest followed by *F. hookeri* and *M. philippensis* each having 0.062%. There was a continuous increase in N concentration (Figure 3b) of residual litter throughout the decomposition cycle in all the species, thus showing significant (p<0.05, except in the case of *F. hookeri*) inverse linear relationship. At the end of the study period, the N concentration was more than one and half times higher than the initial in the case of all the species except *F. hookeri* whose concentration was just slightly higher than that at the initial phase. Similar to the findings of this study, an increase in N concentration was observed by Bargali *et al.* (2015), Arslan *et al.* (2010) and Bargali *et al.* (2006). This might have resulted from microbes taking up inorganic N, i.e. fungal immobilization as microbes require nutrients like N and P for their growth, and they have to take sufficient N to use C containing materials (Bargali *et al.*, 1993). Though there was an increasing pattern of nitrogen concentration during the study period, *F. hookeri* might provide mineralized N earlier than other species as this species showed less net change from the initial N content.

Phosphorus concentration

The initial P was found to be highest (0.145%) in *D. pentagyna* followed by *F. hookeri* (0.131%). Similar to the result of N, the correlation between the remaining weight and the P was slightly negative except in the case of *D. pentagyna* which showed a positive relationship with the remaining weight (Figure 3c). However, the relation was not significant for any of the species (p>0.05). This study showed that the net release of P was highest for *S. robusta* followed by *D. pentagyna*.

Potassium concentration

The remaining P concentration with time was more or less similar for all the species. The initial concentration was highest in *F. hookeri* (21.159%) followed by *A. lakoocha* (5.295). The amount of P was found to have dramatically decreased during the first month for all the species and increased in the second month and again decreased in the third month (see Figure 3d). The rate slightly fluctuated again at the last two months of the study period. The net release of P was highest in *F. hookeri* followed by *A. lakoocha*.

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Figure 3a: Remaining OM (%) with time; Figure 3b: Remaining N (%) with time; Figure 3c: Remaining P (%) with time; and Figure 3d: Remaining K (%) with time
Conclusion

Based on the present study, it can be concluded that the rate of decomposition of M. philippensis is highest followed by A. lakoocha whereas the rate of decomposition of S. robusta is lowest. Decomposition is a complex procedure heavily influenced by biotic and abiotic factors. Both decomposition rate-constant and weight loss were highest for M. philippensis (% weight loss = 73.49; k = 0.33) and lowest for S. robusta (% weight loss = 54.01; k = 0.18). In general, the weight remaining was strongly negatively correlated with N and P concentrations but slightly negatively correlated with K concentration. However, there was a strong positive correlation between the remaining OM and C : N ratio for all the species. The study showed that there was no net release of N during the one-year study period, thus indicating none of the species to be the immediate source for N to the soil. However, the net P release was highest for S. robusta followed by D. pentagyna while the net K release was highest in F. hookeri followed by A. lakoocha.

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References

Allan, D. J., and Castillo, M. M. (2007). Stream ecology : structure and function of running waters, 2nd edition. Springer, New York.

Arslan, H., Gurcan, G. and Kirmizi, S. (2010). Nitrogen mineralization in the soil of indigenous oak and pine plantation forests in a Mediterranean environment. European Journal of Soil Biology 46 : 11–17.

Austin, A. T. and Vitousek, P. M. (2000). Precipitation, decomposition and litter decomposability of Metrosideros polymorpha in native forests on Hawaii. Journal of Ecology 88 : 129–138.

Bargali, S. S., Singh, S. P. and Singh, R. P. (1993). Pattern of weight loss and nutrients release from decomposing leaf-litter in age series of eucalypt plantations. Soil Biology and Biochemistry 25 : 1731–1738.

Bargali, S. S., Pandey, C. B. and Sharma, D. K. (2006). Weight loss and nitrogen release pattern in leaf and wood litter of Gliricidia sepium (Jacq.) Walp. Bulletin of the National Institute of Ecology 17 : 25–29.

Bargali, S. S., Shukla, K., Singh, L., Ghosh, L. and Lakhera, M. L. (2015). Leaf-litter decomposition and nutrient dynamics in four tree species of dry deciduous forest. Tropical Ecology 56 (2) : 191–200.

Berg, B. and McClaugherty, C. (2014). Plant litter : decomposition, humus formation, carbon sequestration. Springer-Verlag, Berlin, Germany.

Brady, N. and Weil, R. (2010). The nature and properties of soils. Pearson, Upper Saddle River.

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

Dechaine, J., Ruan, H., Sanchez deLeon, Y. and Zou, X. (2005). Correlation between earthworms and plant-litter decomposition in a tropical wet forest of Puerto Rico. Pedobiologia 49 (6) : 601–607.

Gautam, T. P. and Mandal, T. N. (2016). Effect of disturbance on litter dynamics in moist tropical forest of eastern Nepal. Our Nature 14 (1) : 1–12.

Gilbert, O. and Bocock, K. L. (1960). Changes in the leaf-litter when placed on the surface of soils with contrasting humus types. II. Changes in the nitrogen content of oak...
and ash litter. *Journal of Soil Science* 11 : 10–19.

Guendehou, G. H. S., Liski, J., Tuomi, M., Moudachirou, M., Sinsin, B. and Makipaa, R. (2014). Decomposition and changes in chemical composition of leaf-litter of five dominant tree species in a west African tropical forest. *Tropical Ecology* 55 : 207–220.

Hasanuzzaman, Md. and Hossain, M. (2014). Leaf-litter decomposition and nutrient dynamics associated with common horticultural cropland agroforestry tree species of Bangladesh. *International Journal of Forestry Research* 2014 (1) : pages?

Hauer, R. F. and Lamberti, L. A. (2006). Methods in Stream Ecology. 2nd edition. Academic, Waltham.

Isaac, S. R. and Nair, M. A. (2005). Biodegradation of leaf-litters in the warm humid tropics of Kerala, India. *Soil Biology and Biochemistry* 37 : 1656–1664.

Jackson, M. L. (1967). Soil chemical analysis. Prentice Hall, New Jersey. p. 498.

Kim, J. S. (2007). Litter decomposition and nitrogen release in three *Quercus* species at temperate broad-leaved forest. *Forest Science and Technology* 3 (2) : 123–131.

Olsen, J. S. (1963). Energy storage and the balance of producers and decomposers in ecological systems. *Ecology* 44 : 322–331.

Ross, D. J., Tate, K. R., Newton, P. C. D. and Clark, H. (2002). Decomposability of C3 and C4 Grass-litter sampled under different concentrations of atmospheric carbon dioxide at a natural CO2 spring. *Plant and Soil* 240 (2) : 275–286. doi : 10. 1023/A : 1015779431271.

Saha, S., Rajwar, G. S., Kumar, M. and Upadhaya, K. (2016). Litter production, decomposition and nutrient release of woody tree species in Dhanaulti region of temperate forest in Garhwal Himalaya. *Eurasian Journal of Forest Science* 4 (1) : 17–30.

Salinas, N., Malhi, Y., Silman, M., Cuesta, R. R., Huaman, J., Salinas, D., Huaman, V., Gibaja, A., Mamani, M. and Farfan, F. (2011). The sensitivity of tropical leaf-litter decomposition to temperature results from a large-scale leaf translocation experiment along an elevation gradient in Peruvian forest. *New Phytologist* 189 : 967–977.

Silveira, M. L., Reddy, K. R., and Comerford, N. B. (2011). Litter decomposition and soluble carbon, nitrogen and phosphorus release in a forest ecosystem. *Open Journal of Soil Science* 1 : 86–96.

Singh, L., Singh, A., Bargali, S. S. and Upadhyay, V. P. (2007). Leaf-litter decomposition and nutrient release pattern in multipurpose tree species of central India. *Journal of Basic and Applied Biology* 1 : 14–21.

Usman, S., Singh, S. P., Rawat, Y. S. and Bargali, S. S. (2000). Fine root decomposition and nitrogen mineralization pattern in *Quercus leucotrichophora* and *Pinus roxburghii* forest in central Himalaya. *Forest Ecology and Management* 131 : 191–199.

Wieder, W. R., Cleveland, C. C. and Townsend, A. R. (2009). Control over leaf-litter decomposition in wet tropical forests. *Ecology* 90 (12) : 3333–3341.