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# LEAF LITTER DECOMPOSITION AND NUTRIENT DYNAMICS ASSOCIATED WITH COMMON CROPLAND AGROFOREST TIMBER TREE SPECIES OF BANGLADESH


## SUMMARY

*Melia azadirachta, Azadirachta indica, Eucalyptus camaldulensis, Swietenia macrophylla, Albizia saman, Acacia auriculiformis, Dalbergia sissoo* and *Khaya anthotheca* are the most common cropland agroforest timber species of Bangladesh. This study focused on leaf litter decomposition and soil nutrient (N, P and K) return of these tree species. Leaf litter decomposition rates were determined using the litter bag technique in both dry and wet seasons. Mass loss was highest (70% and 51%) for *M. azadirachta* followed by *A. indica* (50% and 63%), *D. sissoo* (51% and 54%) and the lowest was found for *S. macrophylla* (26% and 29%) in both dry and wet season respectively over 180 day periods. The rate of decomposition was highest (0.407 g/month) for *A. indica* followed by *M. azadirachta* (0.402 g/month) and lowest (0.185 g/month) was observed for *S. macrophylla* in dry season while the rate of decomposition was found highest (0.530 g/month) for *M. azadirachta* followed by *A. indica* (0.480 g/month) and lowest (0.223 g/month) was observed for *S. macrophylla* in wet season. Significant ($p<0.05$) differences were observed among mass loss, and N, P and K concentrations of leaf litter between dry and wet seasons, with highest decomposition in wet season. The highest decay constant was observed for *M. azadirachta* (2.29 and 3.59) followed by *A. indica* (2.19 and 2.74) and the lowest (1.18 and 1.16) was found for *S. macrophylla* in dry and wet seasons, respectively. This study showed that, *M. azadirachta* was the best in terms of nutrient return through leaf litter decomposition followed by *A. indica* and *D. sissoo*.


**Keywords:** Cropland agroforestry, Decay constant, Decomposition, Leaf litter, Nutrient dynamics.

## INTRODUCTION

Agriculture is the major economic activity in Bangladesh (Zashimuddin 2004). Agroforestry in an age old practice in Bangladesh, which satisfies the sustainable management of land, agricultural crops, trees and/or animals simultaneously or sequentially (Hasanuzzaman *et al* 2006). Among different agroforestry practices, cropland agroforestry in an important production system of Bangladesh (Hasanuzzaman *et al* 2014a). Farmers plant trees in the croplands

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for the increased production of timber, fodder, fuel wood, fruits, herbal medicines, raw material of small cottage industries, short-term non-timber products and also for the environmental and ecological benefits (Dwivedi 1992; Ahmed 2001; Ya 2002; Ahmed *et al* 2004; Zashimuddin 2004; Anon 2010; Rahman *et al* 2011). Agroforestry promotes efficient cycling of nutrients than traditional agriculture systems which have shown their ability to hold sustainable agriculture and better environment as well (Dwivedi 1992; Ahmed 2001; Smiley and Kroschel 2010; Mahmood *et al* 2011). A wide variety of timber tree species are practiced in different cropland/other form of agroforest in Bangladesh for fulfilling the increased demand of timber (Ahmed 2001; Zashimuddin 2004; Rahman *et al* 2011; Hasanuzzaman *et al* 2014a). Among these species, *Melia azadirachta, Azadirachta indica, Eucalyptus camaldulensis, Swietenia macrophylla, Albizia saman, Acacia auriculiformis, Dalbergia sissoo* and *Khaya anthotheca* are the common cropland agroforest timber tree species of Bangladesh (Ahmed 2001; Hasanuzzaman *et al* 2014a).

Nutrients are up taken by Plants for their growth and development and a portion of the nutrients are accumulated in plant body (Hasanuzzaman *et al* 2006). A considerable amount of those nutrients are returned to the soil through litter fall which has important role in the biogeochemical cycling of nutrients (Mahmood and Saberi 2005; Hasanuzzaman *et al* 2014bc). Litter improves the soil quality through adding the organic matter and nutrients to the soil (Ngoran *et al* 2006, Mahmood and Hoque 2008, Mahmood *et al* 2009, Traidiati *et al* 2011). Leaf litter is the main and quick source of organic matter and nutrient to the soil compared to other litter parts (Mason 1977, Park and Kang-Hyun 2003, Mahmood *et al* 2011). The nutrients in litter added to the soil through microbial decomposition (Mason 1977; Valiela *et al* 1985; Mahmood *et al* 2011; Mahmood *et al* 2013). However, the amount of nutrient addition through leaf litter decomposition varies from species to species (Marschner 1995; Jones 1998; Mahmood *et al* 2013). The amount of nutrient addition to a particular ecosystem found to vary with the species (Mahmood *et al* 2013) and climatic conditions (Semwal *et al* 2003; Mahmood and Saberi 2005; Mahmood *et al* 2013). Appropriate tree species selection based on nutrient cycling is a vital issue in any agroforestry practice. However, no attempt has been taken to screen the commonly planted tree species in the cropland agroforests as well as other types of agroforest on the basis of nutrient cycling. Therefore, this study aimed to prioritize the commonly planted timber tree species (*M. azadirachta, A. indica, E. camaldulensis, S. macrophylla, A. saman, A. auriculiformis, D. sissoo* and *K. anthotheca*) on the basis of nutrient (N, P and K) return through leaf litter decomposition during dry and wet season.

## MATERIAL AND METHODS

### *Study area*

Bangladesh is located between 20°34'-26°3' N; and 88°01'-92°41' E which is bordered by the Bay of Bengal on the South and India on all other sides along with small part of Myanmar. Southwestern Bangladesh is a low (<10 m above mean sea level) flat, and fertile deltaic plain which is predominated by alluvium soils (BBS 2004). Three districts (administrative unit) i.e. Khulna, Jessore and Satkhira are located at the southwestern Bangladesh, that lies between 22°44'-23°14' N and 89°01'-89°36' E have been selected for this study. A tropical to subtropical monsoon climate characterizes with three distinct seasons i.e. summer (March–May), rainy (June–October), and winter (November–February) in the study area. The monthly average rainfall is 155 mm, the highest average rainfall (339 mm) occurs during the month of June to September and the lowest average rainfall (16 mm) occurs in the month of November to February in southwestern Bangladesh. January is the coldest and May is the warmest month around the year. The mean annual temperature is 26 °C. The highest (86%-88%) average relative humidity during the month of July to August and the lowest (72%-74%) during the month of February to April prevails in the study area (Hasanuzzaman *et al* 2014a).

***Collection and processing of leaf samples***

Bulk of yellowish senescence leaves of *M. azadirachta*, *A. indica*, *E. camaldulensis*, *S. macrophylla*, *A. saman*, *A. auriculiformis*, *D. sissoo* and *K. anthotheca* were picked from trees of selected cropland agroforest. Leaves of individual species were thoroughly mixed and five grams of leaves were considered as individual sample.

***Experimental setup***

The decomposition study of leaf litter was conducted by using litter bag technique (Mahmood *et al* 2011). Five grams of leaf litter was placed into 300 x 150 mm nylon bag with 1 $mm^2$ mesh size. A total of 90 litter bags for each species were prepared and placed in the selected cropland for each season (dry and wet). Ten bags were brought back to the laboratory for calculating conversion ratio of fresh to oven-dry weight at 80 °C to constant weight.

***Sample Collection and processing***

Ten bags were collected at every ten days interval for the initial month and subsequently at monthly interval for the remaining five months. The collected leaf litter samples were gently washed and all sediments and dirt particles was then removed by using a soft brush with running tap water followed by final rinsing in distilled water. Each sample was then oven-dried at 80 °C to constant weight.

***Mass loss and decay constant***

The loss in dry mass of leaf samples was calculated from the initial converted oven-dry mass and remaining mass. The rate of decomposition was calculated from the percentage of mass loss divided by respective days of sample collection. Decay constants for leaf litter were calculated using negative exponential decay model.

$$X / X_0 = \exp^{(-kt)}$$ (Olson 1963)

where, $X$ is the weight remaining at time $t$, $X_0$ the initial weight, exp the base of natural logarithm, $k$ the decay rate coefficient and $t$ is the time (days) in year.

***Nutrients concentration in leaf litter***

The oven-dried leaf samples of the selected species were grounded, processed and acid digestion according to (Allen 1974). The digested sample extracts were processed according to (Weatherburn 1967) and (Timothy *et al* 1984) to measure nitrogen and phosphorus concentration in sample extracts respectively using UV-Visible Recording Spectrophotometer (U-2910, HITACHI, Japan). Potassium concentration in sample extracts was measured by Flame photometer (PFP7, Jenway LTD, England). The amount of nutrient released from leaf litters were calculated as differences between initial and final absolute amounts also expressed as percentage of initial amount.

***Statistical analysis***

The relationship of mass loss, N, P and K concentrations of leaf litter of the studied tree species between dry and wet season was evaluated by unpaired t test using SPSS (17) statistical software. The rate of decomposition among the studied tree species in each season (dry and wet) were compared by ANOVA analysis followed by Duncan Multiple Range Test (DMRT) using SAS statistical software. Moreover, the relationship among mass loss and site factors (monthly rainfall and temperature) were evaluated by regression analysis using SAS 6.12 statistical software.

## RESULTS AND DISCUSSION

***Mass loss and microbial decomposition***

The mass loss due to microbial decomposition found to vary significantly ($p<0.05$) at different time interval during the dry and wet season for all the studied tree species (Table 1). Comparatively highest (51% and 70%) mass loss was found for *M. azadirachta* followed by *A. indica* (50% and 63%) and the lowest (25% and 25%) was observed for *L. chinensis* during 180 days in the dry and wet seasons, respectively (Fig. 1). The rate of decomposition was found the highest (0.407 g/month) for *A. indica* followed by *M. azadirachta* (0.402 g/month) and the lowest (0.185 g/month) was observed for *S. macrophylla* in dry season while the rate of decomposition was found the highest (0.530 g/month) for *M. azadirachta* followed by *A. indica* (0.480 g/month) and the lowest (0.223 g/month) was observed for *S. macrophylla* in wet season (Fig. 2). The mass loss pattern and rate of decomposition showed differences among the studied tree species (Figs. 1, 2) may be due to the litter quality, the presence of varying amounts of water soluble phenolic compounds, flavanoids, tannin, physical and chemical properties of leaf litter and the presence of thick waxy cuticle (Mason 1977; Cundell et al. 1979; Simlai and Roy 2012; Mahmood et al. 2013).

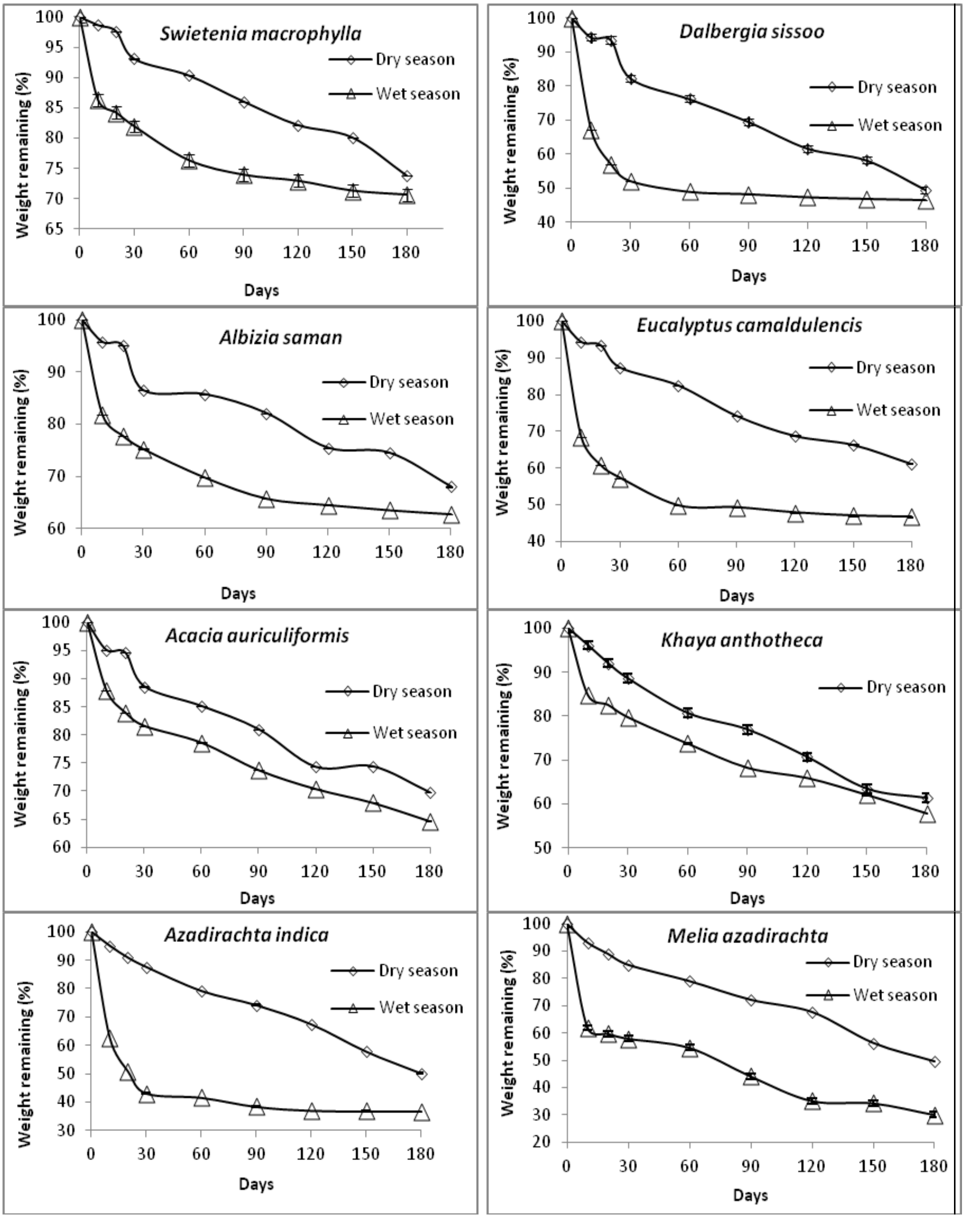


Figure 1. Mass loss of leaf litter due to microbial decomposition

Mass loss of leaf litter decreased gradually during the experiment in dry and wet season due to decomposition (Mahmood et al. 2011, 2013). Higher mass loss of leaf litter was found during the first 30 days, followed by a gradual mass loss for the subsequent 150 days (Fig. 1) which indicates two stages i.e. initial stage and advanced stage (Takeda 1995; Semwal et al. 2003).

Table 1. Significant test of mass loss of leaf litter of selected cropland agroforest tree species in dry and wet season.

| Name of species | 0 days | 10 days | 20 days | 30 days | 60 days | 90 days | 120 days | 150 days | 180 days |
|---|---|---|---|---|---|---|---|---|---|
| *S. macrophylla* | 35.36 P=0.001 | 44.82 P=0.001 | 52.18 P=0.001 | 24.89 P=0.001 | 59.11 P=0.001 | 48.93 P=0.001 | 32.10 P=0.001 | 30.26 p=0.001 | 3.11 p=0.05 |
| *D. sissoo* | 24.04 P=0.001 | 147.50 P=0.001 | 206.05 P=0.001 | 169.17 P=0.001 | 152.31 P=0.001 | 115.97 P=0.001 | 73.96 P=0.001 | 55.72 p=0.001 | 5.09 p=0.018 |
| *A. saman* | 15.57 P=0.002 | 74.82 P=0.001 | 96.03 P=0.001 | 58.69 P=0.001 | 89.24 P=0.001 | 92.35 P=0.001 | 58.55 P=0.001 | 58.97 P=0.001 | 23.33 P=0.001 |
| *E. camaldulensis* | 12.73 P=0.003 | 154.43 P=0.001 | 198.98 P=0.001 | 183.14 P=0.001 | 201.10 P=0.001 | 152.88 P=0.001 | 127.70 P=0.001 | 117.95 P=0.001 | 87.82 P=0.001 |
| *A. auriculiformis* | 45.25 P=0.001 | 3.39 P=0.038 | 26.45 P=0.001 | 5.52 P=0.016 | 3.82 P=0.031 | 10.61 P=0.004 | 8.20 P=0.007 | 8.49 P=0.007 | 1.70 P=0.117 |
| *K. anthotheca* | 29.70 P=0.001 | 44.97 P=0.001 | 34.51 P=0.001 | 31.82 P=0.001 | 23.05 P=0.001 | 35.92 P=0.001 | 13.29 P=0.003 | 5.23 P=0.017 | 9.33 P=0.006 |
| *A. indica* | 4.24 P=0.024 | 159.52 P=0.001 | 211.00 P=0.001 | 240.84 P=0.001 | 200.54 P=0.001 | 191.06 P=0.001 | 159.52 P=0.001 | 103.66 P=0.001 | 58.12 P=0.001 |
| *M. azadirachta* | 5.67 P=0.015 | 170.27 P=0.001 | 159.66 P=0.001 | 147.08 P=0.001 | 132.79 P=0.001 | 159.10 P=0.001 | 190.21 P=0.001 | 127.70 P=0.001 | 114.55 P=0.001 |

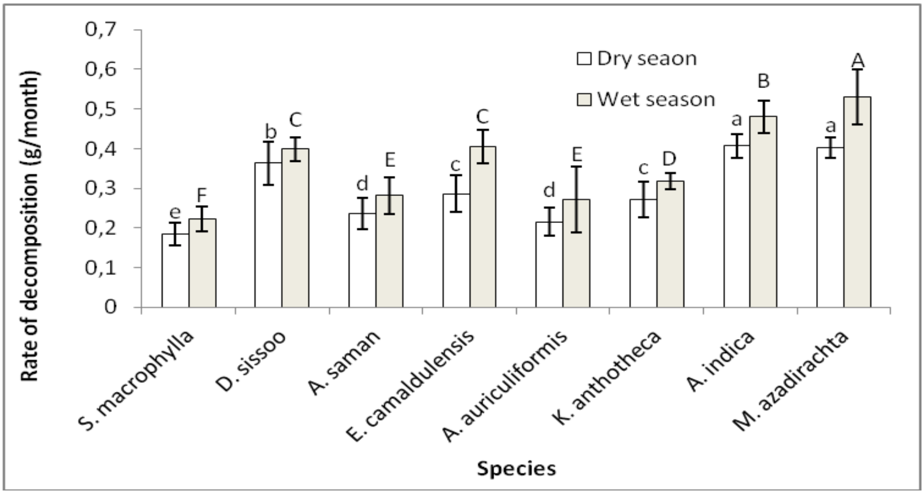


Figure 2 Rate of decomposition (g/month) of leaf litter due to microbial decomposition

In the initial stage, relatively larger decrease in mass was observed due to leaching of readily soluble substances and non-lignified carbohydrates (Ibrahima et al. 2008, 2010; Mahmood et al. 2007, 2011; Hasanuzzaman et al. 2014f). While in the advanced stage, the further decrease in mass loss may be attributed due to the release of higher percentage of recalcitrant fractions like cellulose, lignin and tannin of leaf litter (Bloomfield et al. 1993). The shorter half-life was found for wet season and higher half-life was found for dry season (Table 2) may be attributed to microclimatic variations (Verhoef and Gunadi 2001; Mahmood et al. 2011).

Table 2. Average decay constant and half-life ($t_{50}$) of leaf litter of selected tree species during decomposition in dry and wet season

| Name of Species | Dry season | | Wet season | |
|---|---|---|---|---|
| | Average decay constant (K) | $t_{50}$ (Days) | Average decay constant (K) | $t_{50}$ (Days) |
| *M. azadirachta* | 2.29 | 111 | 3.59 | 71 |
| *A. indica* | 2.19 | 116 | 2.74 | 92 |
| *D. sissoo* | 2.13 | 119 | 2.18 | 116 |
| *E. camaldulensis* | 1.53 | 166 | 2.18 | 116 |
| *K. anthotheca* | 1.55 | 163 | 1.61 | 157 |
| *A. saman* | 1.26 | 200 | 1.41 | 179 |
| *A. auriculiformis* | 1.29 | 197 | 1.30 | 195 |
| *S. macrophylla* | 1.18 | 215 | 1.16 | 218 |

Table 3. Relationship among rainfall and temperature with mass loss of leaf litter of selected cropland agroforest tree species (dry and wet season)

| Name of species | Rainfall Vs Mass Loss Relationship (Regression coefficient and *F*-value) | | Temperature Vs Mass Loss Relationship (Regression coefficient and *F*-value) | |
|---|---|---|---|---|
| | Dry season | Wet season | Dry season | Wet season |
| *M. azadirachta* | $R^2$=0.42, *F*=2.86 | $R^2$=0.93, *F*=57.39 | $R^2$=0.46, *F*=3.47 | $R^2$=0.06, *F*=0.24 |
| *A. indica* | $R^2$=0.37, *F*=2.34 | $R^2$=0.91, *F*=40.25 | $R^2$=0.43, *F*=3.13 | $R^2$=0.05, *F*=0.21 |
| *D. sissoo* | $R^2$=0.33, *F*=1.99 | $R^2$=0.74, *F*=11.50 | $R^2$=0.39, *F*=2.53 | $R^2$=0.01, *F*=0.01 |
| *E. camaldulensis* | $R^2$=0.26, *F*=1.43 | $R^2$=0.63, *F*=6.72 | $R^2$=0.29, *F*=1.66 | $R^2$=0.01, *F*=0.01 |
| *K. anthotheca* | $R^2$=0.27, *F*=1.49 | $R^2$=0.82, *F*=17.72 | $R^2$=0.35, *F*=2.17 | $R^2$=0.04, *F*=0.17 |
| *A. saman* | $R^2$=0.45, *F*=3.22 | $R^2$=0.80, *F*=16.01 | $R^2$=0.51, *F*=4.20 | $R^2$=0.09, *F*=0.37 |
| *A. auriculiformis* | $R^2$=0.27, *F*=1.45 | $R^2$=0.87, *F*=27.89 | $R^2$=0.33, *F*=1.98 | $R^2$=0.01, *F*=0.01 |
| *S. macrophylla* | $R^2$=0.38, *F*=2.49 | $R^2$=0.77, *F*=13.20 | $R^2$=0.42, *F*=2.94 | $R^2$=0.03, *F*=0.13 |

The decay constant (k) was found the highest (2.29 and 3.59) for *M. azadirachta* followed by *A. indica* (2.19 and 2.74) and the lowest (1.18 and 1.16) was found for *S. macrophylla* in dry and wet season respectively (Table 2). Conversely highest half-life was found for *S. macrophylla* (215 days and 218 days) followed by *A. auriculiformis* (197 days and 195 days) and the lowest (111 days and 71 days) was observed for *M. azadirachta* in dry and wet season respectively (Table 2). The microbial decomposition rate of leaf litter of the studied tree species showed significant ($p<0.05$) relationship with rainfall in both dry and wet season and the relationship with temperature was significant in dry season but not significant in wet season (Table 3). The decay constant range, k=

2.29−1.18 in dry season and k = 3.59−1.16 in wet season was found for this study while k= 3.46-2.35 was found for three tropical agroforestry tree species (*Mangifera indica*, *Artocarpus heterophyllus* and *Anacardium occidentale* as reported by Isaac and Nair (2005). Alvarez et al. (1992) reported that, k value is often greater than 1.0 for tropical forests indicating that leaf litter turnover occurred in a year or less than a year. The higher range of decay constant was found in wet season than dry season because of site factors i.e. rainfall also reported by Semwal et al. (2003) and Isaac and Nair (2005). The decay constant varied from species to species (Table 2) also reported by Mahmood (Mahmood et al. 2011, 2013; Hasanuzzaman et al. 2014de) as well as varied within a species for the differences in the length of decomposition period and different land use types (Triadiati et al. 2011). The highest rate of leaf litter decomposition of *M. azadirachta* could be an indicator of higher litter quality, compared to other studied tree species also reported by Mahmood et al. (2011) and Hasanuzzaman et al. (2014d).

***Nutrients at different stages of microbial decomposition process***

The nutrients concentration found to decrease gradually at the end of the experiment (180 days) in dry season (Figs. 3, 4 and 5). Conversely, nutrients concentration increased at the end of experiment in wet season (Figs. 3, 4 and 5). However, rapid decrease in P concentration was observed at the end of first month, while rapid decrease in K concentration was reported within 10 days of leaf litter decomposition in wet season (Figs. 3, 4 and 5). The highest concentration of initial N (13.82 mg/g and 12.6 mg/g) was detected for the leaf litter of *M. azadirachta* followed by *D. sissoo* (12.98 mg/g and 12.44 mg/g) and the lowest concentration of N (5.72 mg/g and 5.91 mg/g) was found for *S. macrophylla* in dry and wet season respectively (Fig. 3). The highest concentration of initial P (9.48 mg/g and 10.17 mg/g) was detected for the leaf litter of *M. azadirachta* followed by *A. indica* (6.54 mg/g and 6.89 mg/g) and the lowest concentration of P (0.62 mg/g and 0.83 mg/g) was found for *A. auriculiformis* in dry and wet season respectively (Fig. 4). The highest concentration of initial K (22.11 mg/g and 22.32 mg/g) was detected for the leaf litter of *A. indica* followed by *M. azadirachta* (19.60 mg/g and 18.62 mg/g) and the lowest concentration of N (12.80 mg/g and 12.56 mg/g) was found for *K. anthotheca* in dry and wet season respectively (Fig. 5). The nutrient concentrations (N, P and K) showed significant ($p<0.05$) differences among dry and wet season experiment (Table 4, 5 and 6). Leaf litter of the studied species showed a similar pattern (K>N>P) of decreasing nutrient concentration throughout the decomposition process (Fig. 3, 4 and 5). The highest concentrations of N (55 and 40 mg/g) and P (31 and 39 mg/g) were added to the soil from the leaf litter of *M. azadirachta* where as the highest K (70 and 74 mg/g) concentration was added to the soil from the leaf litter of *A. indica* and the lowest concentration of N (13 and 1 mg/g) were added to the soil through leaf litter of *S. macrophylla* and the lowest P (2 and 0.08 mg/g) and K (28 and 32 mg/g) concentration was added to the soil from leaf litter of *A. auriculiformis* in dry and wet season respectively (Table 4).

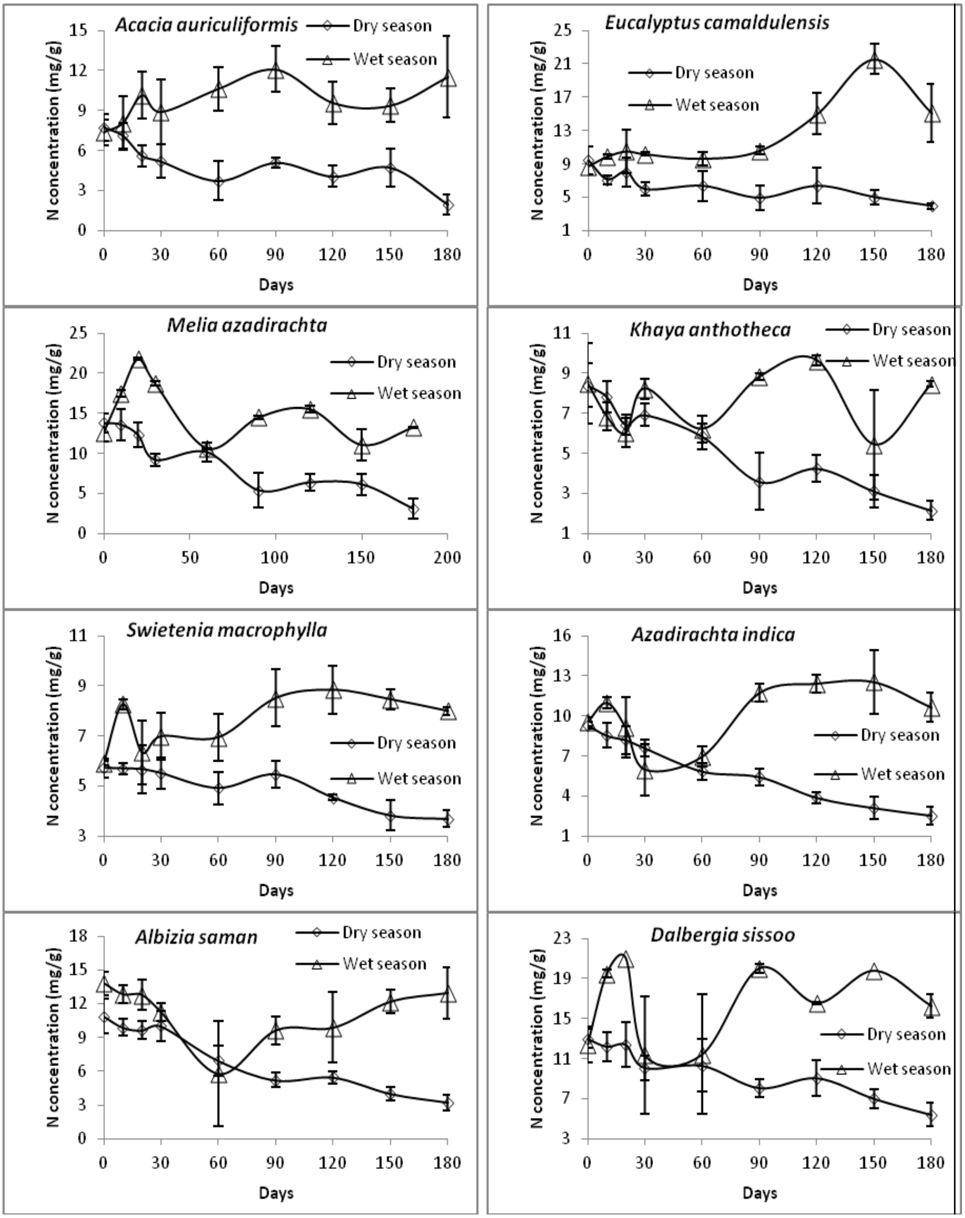


Figure 3. N concentration (mg/g) of leaf litter due to microbial decomposition

The variation in nutrients (N, P and K) concentration in the leaf litter of the studied species at the initial stages of decomposition were found as the selected tree species were from different families having variation in the rate of nutrient uptake, chemical and biochemical properties of leaf litter (Elevitch and Wilkinson 1998; Mahmood and Saberi 2007; Mahmood et al. 2009).

Comparatively higher initial concentration of N, P and K in leaf litter of *M. azadirachta* and *A. indica* indicated that capabilities of these species to retranslocate these nutrients were lower during the senescence of leaves (Berg and Laskowski 2006; Hagen-Thorn et al. 2006, Mahmood et al. 2011).

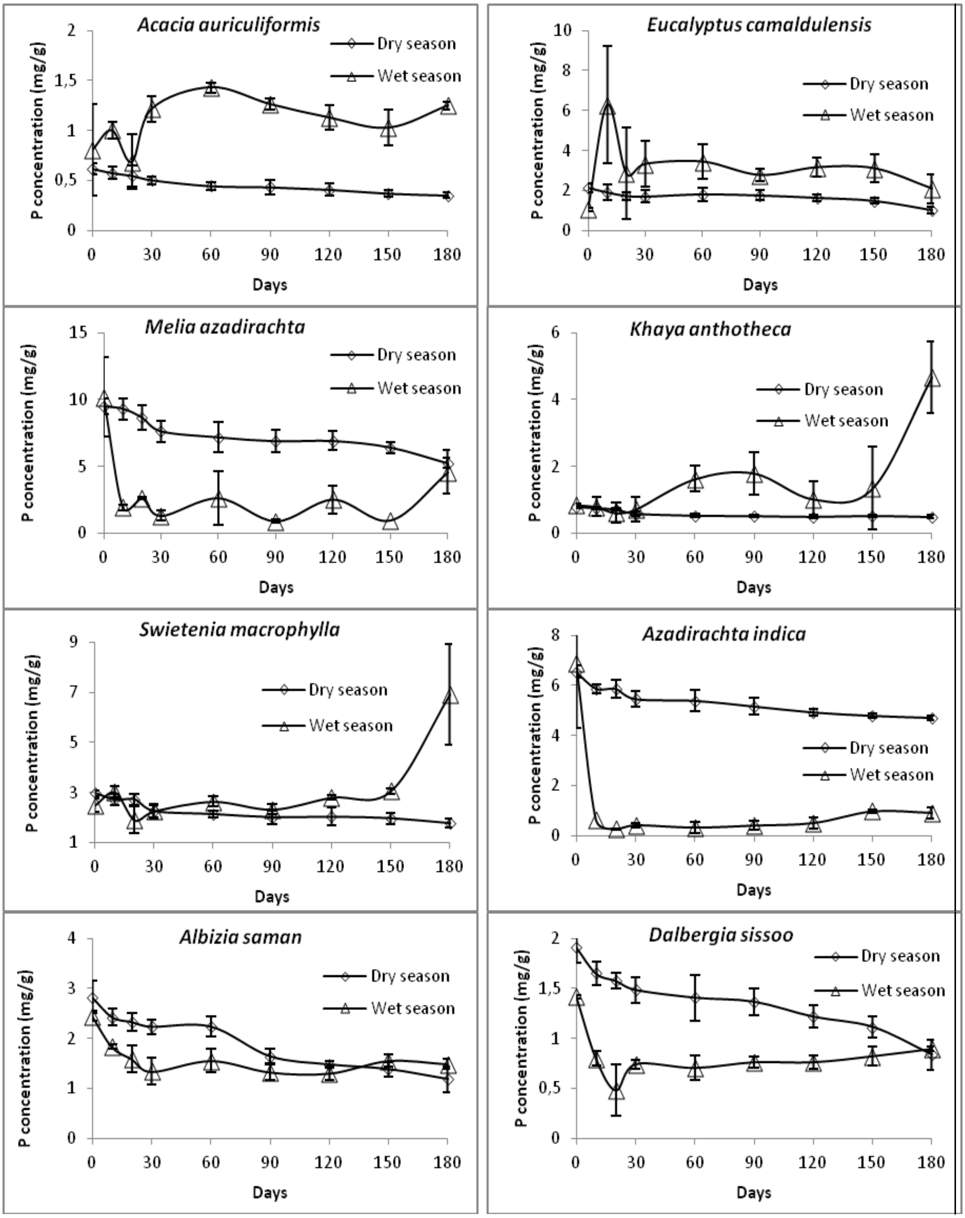


Figure 4. P concentration (mg/g) of leaf litter due to microbial decomposition

The faster decreasing of K concentration from leaf litter was observed as it is a non-structural element and highly mobile to be the most leachable cation during the decomposition of litter (Tisdale et al. 1993; Marschner, 1995; Herra´ez and Ferna´ndez Marcos 2000; Guo and Sims 2002). While N is structurally bound with cell wall and leaf contained comparatively lower concentration of P (Meyer et al., 1973, DeFelice, 1993; Mahmood et al. 2011).

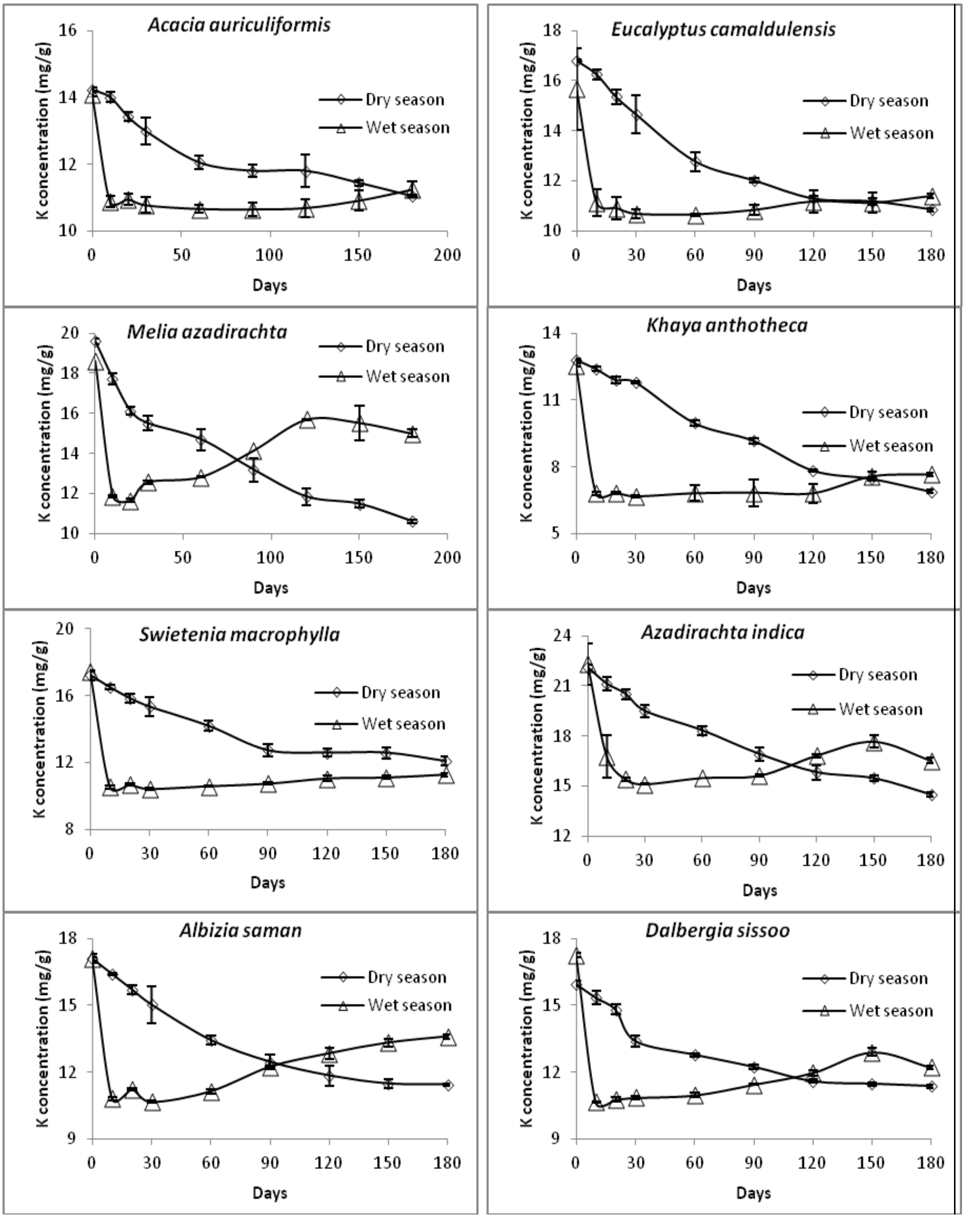


Figure 5. K concentration (mg/g) of leaf litter due to microbial decomposition

The initial rapid decrease of nutrients concentration (Fig. 3, 4 and 5) was observed may be due to the loss of the soluble forms of nutrients at the initial stages of decomposition (Mahmood et al. 2007) and a slower release of nutrients at the later stages of leaf litter decomposition governed by microbial oxidation of refractory components and physical and biological fragmentation (Herra´ez and Ferna´ndez Marcos 2000, Mahmood et al. 2013).

On the contrary, increased concentration of nutrients (N, P and K) at different stages of decomposition in wet season (Fig. 3, 4 and 5) was attributed to microbial or non-microbial immobilization in the residual leaf litter while leaf litter acts as a surface for fungi or heterotrophic organisms (Lin et al. 2007; Mahmood et al. 2011, 2013).

Table 4. Nutrient added through leaf litter decomposition of timber tree species in dry and wet season

| Species | N concentration (mg/g) | | P concentration (mg/g) | | K concentration (mg/g) | |
|---|---|---|---|---|---|---|
| | Dry season | Wet season | Dry season | Wet season | Dry season | Wet season |
| *M. azadirachta* | 54.80 | 39.36 | 31.35 | 39.04 | 65.27 | 63.61 |
| *A. indica* | 36.89 | 25.75 | 19.78 | 29.83 | 69.70 | 73.85 |
| *D. sissoo* | 44.48 | 21.70 | 6.49 | 4.49 | 44.67 | 51.81 |
| *E. camaldulensis* | 30.99 | 7.70 | 6.70 | 0.43 | 44.96 | 46.95 |
| *K. anthotheca* | 30.22 | 16.32 | 2.01 | 8.40 | 35.85 | 36.81 |
| *A. saman* | 38.58 | 25.86 | 8.95 | 6.88 | 41.25 | 38.83 |
| *A. auriculiformis* | 27.26 | 1.98 | 1.59 | 0.08 | 28.01 | 31.51 |
| *S. macrophylla* | 12.68 | 1.32 | 7.04 | 10.53 | 35.16 | 42.79 |

## CONCLUSION

A considerable amount of organic matter and nutrients added to the soil through the process of leaf litter decomposition and a portion of these organic matter and nutrients would be reused by the plants. More organic matter and nutrients can be added to the soil through the process of leaf litter decomposition during wet season because of higher rate of decomposition in wet season than dry season.

The added nutrients may contribute to the sustainability of soil fertility, which is becoming an important phenomenon for agroforestry practices. Among the considered tree species, *M. azadirachta* was the best in terms of nutrient return through leaf litter decomposition followed by *A. indica* and *D. sissoo*.

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