International Research Journal of Biological Sciences ISSN 2278-3202
Vol. **3(8),** 82-88, August **(2014)** *Int. Res. J. Biological Sci.*

Nutrient Return through Leaf litter Decomposition of Common Cropland Agroforest Tree Species of Bangladesh

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Available online at: www.isca.in, www.isca.me
Received 5th March 2014, revised 26th May 2014, accepted 27th June 2014

Abstract

Cropland agroforestry is an important production system in Bangladesh. Melia azadirachta, Azadirachta indica, Eucalyptus camaldulensis, Swietenia macrophylla, Mangifera indica, Zizyphus jujuba, Litchi chinensis, Albizia saman, Artocarpus heterophyllus, Acacia auriculiformis, Dalbergia sissoo and Khaya anthotheca are common in the cropland agroforest of Bangladesh and have been selected for this study. This study focused on the mass loss of leaf litter and nutrient (N, P and K) addition in soil through the microbial decomposition of leaf litter of the selected cropland agroforest tree species of Bangladesh. Leaf litter decomposition experiment was conducted using litter bag technique both in dry and wet season in a controlled environment. The mass loss was found the highest (57% and 63%) for M. azadirachta followed by E, camaldulensis (50% and 56%), A. indica (53% and 58%) and the lowest (11% and 19%) was found for L. chinensis in dry and wet season respectively. The highest rate of decomposition (0.32 g/day and 0.35 g/day) was observed for M. azadirachta and the lowest (0.06 g/day and 0.10 g/day) was detected for L. chinensis. Significant (p=0.05) differences were observed among the mass loss of leaf litter and N, P and K concentration of decomposed soil of the studied species between dry and wet season. The decay constant (k) was found the highest for M. azadirachta (0.005 and 0.005) followed by E. camaldulensis (0.004 and 0.005), A. indica (0.004 and 0.005) and the lowest for L. chinensis (0.001 and 0.001) in dry and wet season respectively. A similar pattern of nutrient concentration (P> K> N) in the decomposed soil of the entire studied tree species were observed. Among the considered cropland agroforest tree species, M. azadirachta was found to be the best followed by, E. camaldulensis, L. chinensis and A. heterophyllus in terms of N, P and K return.

Keywords: Cropland agroforestry, leaf litter decomposition, decay constant, organic matter, nutrient return, species selection.

Introduction

Bangladesh is one of the densely populated countries of the world with a population of over 150 million within a territory of 1, 42, 776 km^2. About 80 % of the total population lives in the rural areas whose livelihood is dependent on agriculture and related activities[1]. Farmers plant trees in the croplands 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[2-7]. Agroforestry promotes efficient cycling of nutrients than traditional agriculture systems which have shown their ability to hold sustainable agriculture and better environment as well[2-3,8-9]. A wide variety of tree species are practiced in different cropland/other form of agroforest in Bangladesh[3,6,7]. Among these species, *Melia azadirachta, Azadirachta indica, Eucalyptus camaldulensis, Swietenia macrophylla, Mangifera indica, Zizyphus jujuba, Litchi chinensis, Albizia saman, Artocarpus heterophyllus, Acacia auriculiformis, Dalbergia sissoo* and *Khaya anthotheca* are common in the cropland agroforest of Bangladesh[10-11].

Nutrients are up taken by Plants and a portion of these nutrients are accumulated in plant body[12]. Conversely, a major portion of the up taken nutrients are returned back to the soil through litter fall[13]. Litter improves the soil quality through the addition of organic matter and nutrients to the soil[14-17]. Highest amount of organic matter and nutrients are returned back to the soil through leaf litter in comparison with the other parts of litter[9,18-19]. The nutrients of litter addition to the soil is dependent on microbial decomposition and leaching of minerals and soluble components followed by microbial oxidation of refractory components[9,18,20-21]. However, the amount of nutrient addition through litter decomposition varies from species to species[21-23]. Appropriate tree species selection based on nutrient cycling is a vital issue in agroforestry practice. However, no attempt has been taken to screen or prioritized the commonly planted tree species in the cropland agroforests as well as other types of agroforest on the basis of nutrient cycling. The amount of nutrient addition to the particular ecosystem found to vary with the species[21] and other climatic conditions i.e. rainfall[13,21,24]. This study was conducted in a laboratory condition to observe the actual nutrient return through microbial decomposition of leaf litter of the selected tree species both in dry and wet season. A few studies focused on the nutrient release pattern through leaf litter decomposition of agroforest tree species of Bangladesh[9]. However, no attempt has been taken to screen the nutrient return through microbial decomposition of leaf litter of the agroforest tree species to the soil. Therefore, this study aimed to prioritize the commonly planted cropland agroforest tree species of Bangladesh on the basis of nutrients (N, P and K) return to the soil through microbial decomposition of leaf litter.

Material and Methods

Description of the study area: Bangladesh is located between 20°34'-26°3' N; and 88°01'-92°41' E, on the South bordered by the Bay of Bengal and on all the other sides India along with a small part of Myanmar. Khulna, Jessore and Satkhira districts are located at the southwestern Bangladesh that characterizes low, flat, and fertile deltaic plain predominated by calcareous to noncalcareous alluvium soils[25]. A tropical to subtropical monsoon climate characterizes with three distinct seasons i.e. summer, rainy and winter in this region[26]. The average of monthly 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 the study area. January is the coldest month and May is the warmest month of the years. The mean annual temperature is 26 °C with a range of 22–31 °C. The average relative humidity is the highest (86%-88%) during the month of July to August and the lowest (72%-74%) during February to April[11].

Collection and processing of leaf samples: Bulk of yellowish senescence leaves of *M. azadirachta, A. indica, E. camaldulensis, S. macrophylla, M. indica, Z. jujuba, L. chinensis, A. saman, A. heterophyllus, A. auriculiformis, D. sissoo* and *K. anthotheca* were picked from trees of selected cropland agroforest. Leaves of individual species were thoroughly mixed and 100 grams of leaves were considered as individual sample.

Experimental setup: The microbial decomposition of leaf litter of the selected tree species was conducted by using litter bag technique[9]. The experiment was conducted at the glass house of Forestry and Wood Technology Discipline Nursery, Khulna University. The experiment was conducted during April, 2013 to September, 2013 for both dry and wet season but dry and wet season was manually controlled on the basis of the previous year's daily rainfall data. Dry season was controlled following the rainfall of October to March, 2012 and wet season was controlled following the rainfall of April to September, 2012. A total of 12 species were tested and for each species 6 plastic bowls (3 replicate for dry season and 3 replicate for wet season) were prepared with 10 kg of air dried soil. At the same time 1 kg of air dried soil was brought to the laboratory for measuring the initial nutrient and organic matter status of soil. Individual leaf samples were placed in every litter bag (30 x 20 cm) with 1 mm^2 mesh size. 6 litter bags of each species were prepared for dry and wet season study and 3 litter bags of each species was brought to the laboratory for calculating conversion ratio of fresh to oven-dry weight at 80 °C to constant weight. Each litter bag was placed in single bowl. Thus a total of 72 bowls with 72 litter bags was prepared (36 for dry and 36 for wet season) for the selected 12 species. Water was supplied to the bowls considering the previous year's rainfall data discussed earlier. At the end of experiment (6 month) litter bags were removed from the bowls and the soils were thoroughly mixed. The soils were then air dried for further analysis.

Sample Collection and processing: Litter bags were collected from the glass house at the end of six months experiment (dry and wet season). The collected leaf litter samples were washed gently and the sediments and dirt particles were removed using a soft brush with running tap water and final rinsing by distilled water. Each leaf litter sample was then oven-dried at 80 °C to constant weight. After the collection of leaf litter bags, the soil samples were mixed thoroughly and air dried. The air dried soil samples were then brought in the Nutrient Dynamics Laboratory for chemical analysis. The decomposed soil sample of each species was then oven-dried at 80 °C to constant weight.

Mass loss and decay constant: The amount of mass loss of leaf litter of the studied tree species was calculated from the initial converted oven-dry mass and the remaining mass at the end of experiment. The decomposition rate of leaf litter was calculated from the mass loss (%) divided by duration of decomposition period (days). Decay constants were calculated using negative exponential decay model for leaf litter of the studied species.

$$X / X_0 = \exp^{(-kt)}$$ [27]

where, X-final weight 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.

Organic matter and nutrients addition through leaf litter decomposition: Soil organic matter content addition through microbial decomposition of leaf litter of the studied species was determined by ignition method[28]. One gram soil sample of oven-dried at 105ºC was taken in a porcelain cup and placed in a muffle furnace (Wise Therm, FH-05, DAIHAN Scientific co. ltd, Korea) and kept at 450 ºC for four hours. After cooling to room temperature, the weight of the ignited sample was taken. Percentage of loss on ignition was calculated from the following calculation.

$$\text{Loss on ignition (\%)} = \frac{\text{Loss of weight (g)}}{\text{Oven dry weight (g)}} \times 100$$

The amount of organic matter added through leaf litter decomposition of the studied species was calculated from the initial soil and the soil collected at the end of experiment of each species.

The plant available form of nitrogen in soil was extracted following Mulvaney[29] and the plant available form of phosphorus and potassium in soil was extracted following Williams and Stewart[30] using an orbital shaker (STUART SCIENTIFIC, UK) and the samples were then filtered. The filtered soil samples were processed according to Weatherburn[31] and Timothy et al.[32] to measure nitrogen and phosphorus concentration in soil sample using UV-Visible Recording Spectrophotometer respectively (U-2910, HITACHI, Japan). Potassium concentration in soil sample was measured using Flame photometer (PFP7, Jenway LTD, England). The amount of nutrients (N, P and K) added in soil through leaf litter decomposition of the studied tree species was calculated from the initial soil and the soil collected at the end of experiment of each species.

Statistical analysis: The relationship among mass loss of leaf litter; organic matter, N, P and K concentrations of decomposed soil of the studied tree species between dry and wet season was evaluated by unpaired t test using SPSS (17) statistical software.

Results and Discussion

Mass loss and microbial decomposition: The highest (57% and 63%) mass loss of leaf litter was found for *M. azadirachta* during dry and wet season while the lowest (11% and 19%) was observed for *L. chinensis* (table 1). The rate of decomposition was found the highest (0.32 g/day and 0.35 g/day) for *M. azadirachta* followed by *A. indica* (0.29 g/day and 0.32 g/day) and the lowest (0.06 g/day and 0.10 g/day) was observed for *L. chinensis* in dry and wet season respectively. The mass loss and rate of decomposition showed significant (p=0.05) differences among the studied tree species may be due to the litter quality, the presence of varying amounts of water soluble phenolic compounds, flavanoids, tannin, physicochemical properties of leaf litter and the presence of thick waxy cuticle[18,21,33-34]. The mass loss was observed due to the leaching of minerals, readily soluble substances and carbohydrates (non-lignified)[9,21,35-37] as well as the release of cellulose, lignin and tannin of leaf litter[37]. The mass loss of leaf litter of the studied tree species found to vary significantly (p=0.05) among dry and wet season experiment (table 4) may be due to the variation of rainfall[24]. The decay constant (k) was found the highest for *M. azadirachta* (0.005 and 0.005) followed by *E. camaldulensis* (0.004 and 0.005), *A. indica* (0.004 and 0.005) and the lowest for *L. chinensis* (0.001 and 0.001) in dry and wet season respectively (table 2). The higher range of decay constant (Table 2) was found in wet season than dry season because of site factors i.e. rainfall also reported by Semwal et al.,[24] and Isaac and Nair[39]. Conversely highest half-life was found for *L. chinensis* (1117 and 608) followed by *K. anthotheca* (838 and 436), *A. saman* (664 and 558) and the lowest was found for *M. azadirachta* (146 and 127) days in dry and wet season respectively (table 2). 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 (rainfall) variations[9,38]. The value of decay constant varied for different species (table 2) which was also reported by Mahmood et al.,[9,21]. The highest microbial decomposition rate of leaf litter of *M. azadirachta* could be an indicator of better quality, compared to the litter of other studied tree species also reported by Mahmood et al.,[9].

Organic matter and nutrients addition through leaf litter decomposition: The highest (2.73%) organic matter content was found in the decomposed soil of *A. heterophyllus* followed by *L. chinensis* (2.25%), *A. auriculiformis* (2.00%) and the lowest (1.35%) for *A. indica* in dry season while the highest (3.77%) organic matter content was detected in the decomposed soil of *L. chinensis* followed by *Z. jujuba* (3.40%), *A. auriculiformis* (3.35%) and the lowest (2.60%) was found for *A. saman* in wet season (table 2). The highest (0.157 µg/g) available N concentration was found in the decomposed soil of *D. sissoo* followed by *M. azadirachta* (0.137 µg/g), *A. heterophyllus* (0.117 µg/g) and the lowest (0.004 µg/g) was detected for *M. indica* in dry season while the highest (0.125 µg/g) available N concentration was found in the decomposed soil of *M. azadirachta* followed by *A. indica* (0.115 µg/g), *L. chinensis* (0.088 µg/g) and the lowest (0.006 µg/g) was found for *S. macrophylla* in wet season (Table 3). The highest (10.91 µg/g) available P concentration was found in the decomposed soil of *E. camaldulensis* followed by *K. anthotheca* (8.20 µg/g), *A. saman* (8.055 µg/g) and the lowest (0.58 µg/g) was observed for *M. azadirachta* in dry season while the highest (9.34 µg/g) available P concentration was found in the decomposed soil of *M. azadirachta* followed by *E. camaldulensis* (8.01 µg/g), *M. indica* (7.39 µg/g) and the lowest (0.96 µg/g) was found for *L. chinensis* in wet season (table 3). The highest (0.38 µg/g) available K concentration was found in the decomposed soil of *A. heterophyllus* followed by *Z. jujuba* (0.36 µg/g), *A. indica* (0.29 µg/g) and the lowest (0.004 µg/g) was detected for *M. azadirachta* in dry season while the highest (0.42 µg/g) available K concentration was observed in the decomposed soil of *L. chinensis* followed by *Z. jujuba* (0.37 µg/g), *K. anthotheca* (0.22 µg/g) and the lowest (0.07 µg/g) was detected for *A. heterophyllus* in wet season (table 3). The pattern of nutrients addition (P> K> N) in the decomposed soil was similar for all the studied tree species (table 3). The significant (p=o.o5) variation among organic matter as well as nutrients (N, P and K) concentration in the decomposed soil of the studied species were observed (tables 2 and 3) as the selected tree species were from different families, nutrient release pattern and chemical and biochemical properties of leaf litter[16,40-41]. Comparatively higher amount of organic matter and nutrients (N, P and K) concentration in the decomposed soil of *M. azadirachta*, *E. camaldulensis*, *A. heterophyllus* and *L. chinensis* (table 3) indicated the capabilities of these species to return higher amount of nutrients through microbial decomposition. The organic matter content in decomposed soil of the studied tree species found to vary significantly (p=0.05) among dry and wet season experiment may be for the variation of climatic factors i.e. rainfall but the addition of nutrients (N, P and K) concentrations in the decomposed soil was not varied significantly (p=0.05) among dry and wet season experiment (table 4) may be for the microbial or non-microbial immobilization in the residual leaf litter while leaf litter acts as a surface for fungi or heterotrophic organisms in the wet season experiment[9,21,42].

Table - 1
Mass loss and rate of decomposition of leaf litter of cropland agroforest tree species in dry and wet season

Name of Species	Mass loss (%) of leaf litter		Rate of decomposition (g/day)	
	Dry season	Wet season	Dry season	Wet season
M. azadirachta	57	63	0.32	0.35
E. camaldulensis	50	56	0.28	0.31
A. indica	53	58	0.29	0.32
A. saman	17	20	0.10	0.11
A. auriculiformis	21	36	0.12	0.20
Z. jujuba	36	51	0.20	0.28
K. anthotheca	14	25	0.08	0.14
D. sissoo	36	46	0.20	0.25
M. indica	24	41	0.13	0.23
S. macrophylla	22	31	0.12	0.17
A. heterophyllus	25	44	0.14	0.25
L. chinensis	11	19	0.06	0.10

Table-2
Decay constant, half life and organic matter added through leaf litter decomposition of cropland agroforest tree species in dry and wet season

Name of Species	Decay constant		Half life (t_{50} in days)		Organic matter (%) added in soil	
	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
Melia azadirachta	0.005	0.005	146	127	1.4	3.2
Eucalyptus camaldulensis	0.004	0.005	178	152	1.4	2.85
Azadirachta indica	0.004	0.005	167	144	1.35	2.65
Albizia saman	0.001	0.001	664	558	1.37	2.6
Acacia auriculiformis	0.001	0.003	517	278	2.00	3.35
Zizyphus jujuba	0.002	0.004	282	176	1.87	3.40
Khaya anthotheca	0.001	0.002	838	436	2.00	3.10
Dalbergia sissoo	0.002	0.003	282	203	1.47	2.97
Mangifera indica	0.002	0.003	456	235	1.60	3.30
Swietenia macrophylla	0.001	0.002	509	338	1.45	3.17
Artocarpus heterophyllus	0.002	0.003	431	212	2.73	2.93
Litchi chinensis	0.001	0.001	1117	608	2.25	3.77

Table-3
Nutrients added through leaf litter decomposition of cropland agroforest tree species in southwestern Bangladesh

Name of species	Dry season			Wet season		
	N concentration (µg/g)	P concentration (µg/g)	K concentration (µg/g)	N concentration (µg/g)	P concentration (µg/g)	K concentration (µg/g)
M. indica	0.004	4.340	0.206	0.049	7.388	0.159
A. heterophyllus	0.116	4.531	0.382	0.068	5.579	0.066
L. chinensis	0.048	6.245	0.108	0.088	0.960	0.423
Z. jujuba	0.078	6.769	0.361	0.077	4.055	0.367
K. anthotheca	0.066	8.198	0.102	0.067	4.912	0.216
E. camaldulensis	0.022	10.91	0.066	0.060	8.007	0.149
S. macrophylla	0.024	6.389	0.175	0.006	3.150	0.081
A. auriculiformis	0.098	3.055	0.056	0.083	2.721	0.182
D. sissoo	0.157	0.198	0.123	0.066	3.293	0.190
A. indica	0.071	4.340	0.289	0.115	5.483	0.087
M. azadirachta	0.137	0.579	0.004	0.125	9.340	0.138
A. saman	0.044	8.055	0.035	0.063	7.150	0.074

Table-4
Significant test of mass loss and nutrients concentration among dry and wet season of leaf litter decomposition of cropland agroforest tree species

Name of species	Mass loss	Organic matter	N concentration (µg/g)	P concentration (µg/g)	K concentration (µg/g)
M. azadirachta	12.59, P=0.003	5.20, P=0.061	0.24, P=0.411	2.95, P=0.021	13, P=0.003
E. camaldulensis	16.39, P=0.002	16.74, P=0.019	1.34, P=0.125	4.61, P=0.005	2.22, P=0.078
A. indica	26.61, P=0.001	8.22, P=0.007	0.65, P=0.277	0.24, P=0.412	1.89, P=0.066
A. saman	4.61, P=0.021	2.82, P=0.033	0.33, P=0.380	0.152, P=0.443	0.412, P=0.375
A. auriculiformis	30.11, P=0.001	15.59, P=0.020	0.314, P=0.384	0.089, P=0.467	2.54, P=0.042
Z. jujuba	108.65, P=0.001	8.69, P=0.001	0.03, P=0.488	0.368, P=0.367	0.189, P=0.430
K. anthotheca	116.92, P=0.001	2.28, P=0.043	0.07, P=0.474	0.358, P=0.369	3.57, P=0.012
D. sissoo	68.20, P=0.001	10.06, P=0.001	1.06, P=0.174	0.630, P=0.282	0.69, P=0.263
M. indica	45.13, P=0.001	3.65, P=0.011	1.31, P=0.130	0.57, P=0.301	0.965, P=0.195
S. macrophylla	56.73, P=0.001	4.85, P=0.008	0.455, P=0.347	0.458, P=0.335	5.20, P=0.003
A. heterophyllus	36.82, P=0.001	0.51, P=0.319	1.2, P=0.150	0.198, P=0.426	1.90, P=0.099
L. chinensis	25.99, P=0.001	5.71, P=0.005	0.71, P=0.258	0.87, P=0.216	61,P=0.001

Conclusion

A considerable amount of organic matter and nutrients can be added to the soil of different agroforestry practices through the process of leaf litter decomposition and a portion of these organic matter and nutrients are reused by the plants. The added nutrients can contribute sustainable soil fertility, an important issue for agroforestry practices. Among the considered tree species, *M. azadirachta* was found to be the best followed by, *E. camaldulensis*, *L. chinensis* and *A. heterophyllus* in terms of N, P and K return.

Acknowledgement

Authors wish to thank Bangladesh Academy of Sciences (BAS) and United States Department of Agriculture (USDA) for the financial support and Khulna University (KU) for the logistic supports during the study.

References

1. BBS, Population and Housing Census 2011 Preliminary Results. Bangladesh Bureau of Statistics, Dhaka: Statistics Division, Ministry of Planning, 19 (**2011**)
2. Dwivedi A.P., *Agroforestry Principles and Practices.* India: Oxford and IBH Publishing co. pvt. Ltd, New Delhi, 48-227 (**1992**)
3. Ahmed MFU, Agroforestry in Bangladesh with special reference to northern Bangladesh, In: Haq MF, Hasan MK, Asaduzzaman SM, Ali MY (eds), *Development of agroforestry research in Bangladesh,* Bangladesh: Proceedings of a national workshop on agroforestry research, 16-17 September, Gazipur, 1–10 (**2001**)
4. Ya T., Role of tree in croplands: in Forest and Forest Plants. Accessed on 30/09/2013. http://www.eolss.net/ebooklib, **3** (**2002**)
5. Ahmed MFU, Rahman SML, Ahmed ASMM, Quebedeaux B. Agroforestry as it pertains to vegetable production in Bangladesh, *Journal of Agronomy*, **3**, 282–290 (**2004**)
6. Zashimuddin M., Community forestry for poverty reduction in Bangladesh. In: Sim HC, Appanah S, Lu WM (eds), *Can community forestry make money*? Proceedings of the regional workshop on forest for poverty reduction, 1-2 September, Beijing, China, Available at www.fao.org./docrep/007/ad511e/ad511 e00.htm#Contents. [accessed 05 November 2013] (**2004**)
7. Rahman S.A., Paras F.D., Khan S.R., Imtiaj A., Farhana K.M., Toy M.M., Akhand M.B., Sunderland T., Initiatives of tropical agroforestry to sustainable agriculture: A case study of capasia village, Northern Bangladesh, *Journal of Horticulture and Forestry*, **3**(**4**), 115–121 (**2011**)
8. Smiley G.L. and Kroschel J., Yield development and nutrient dynamics in cocoa-gliricidia agroforests of central Sulawesi, Indonesia, *Agroforestry systems,* **78**, 97-114 (**2010**)
9. Mahmood H., Siddique M.R.H., Rahman M.S., Hossain M.Z., Hasan M.M., Nutrient dynamics associated with leaf litter decomposition of three agroforestry tree species (*Azadirachta indica, Dalbergia sissoo* and *Melia azadirachta)* of Bangladesh, *Journal of Forestry Research,* **22**, 577-582 (**2011**)
10. Quddus M.A., The Cropland Agroforestry Experiences of the Village and Farm Forestry Project in Northwest Bangladesh. Proceedings of National Workshop on Agroforestry, Gazipur, Bangladesh, 229–239 (**2001**)
11. Hasanuzzaman Md., Mahmood H. and Saroar M., Floristic composition and management of cropland agroforest in southwestern Bangladesh, *Journal of forestry research,* DOI-10.1007/s11676-014-0451-4. (**2014**)

12. Hasanuzzaman Md, Mahmood H., Lemon S.H., Islam M,N., Nutrients (P, K and Na) leaching from leaf litter of *Dalbergia Sissoo* (Roxb.), *Pakistan Journal of Forestry,* **56**, 22-29 (**2006**)

13. Mahmood H. and Saberi O., Degradation rate of leaf litter of *Bruguiera parviflora* of mangrove forest of Kuala Selangor, Malaysia, *Indian Journal of Forestry,* **28**,144-149 (**2005**)

14. Ngoran A., Zakra N., Ballo K., Kouamé C., Zapata F., Hofman G. and Van C.O., Litter decomposition of *Acacia auriculiformis* Cunn. Ex Benth. and *Acacia mangium* Willd, under coconut trees on quaternary sandy soils in Ivory Coast, *Biology and Fertility of Soils*, **43**, 102-106 (**2006**)

15. Mahmood H. and Hoque A.K.F., Litter production and decomposition in mangrove- A review, *Indian Journal of Forestry*, **3**, 227-238 (**2008**)

16. Mahmood H., Limon S.H., Rahman M.S., Azad A.K., Islam M.S., Khairuzzaman M. Nutrients (N, P and K) dynamics associated with the leaf litter of two agroforestry tree species of Bangladesh, *iForest,* **2**, 183-186 (**2009**)

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

18. Mason F.C., *Decomposition,* The Institute of Biology's Studies in Biology no. 74. London: Edward Arnold Limited, 219 (**1977**)

19. Park S. and Kang-Hyun C., Nutrient leaching from leaf litter of emergent macrophyte *(Zizania latifolia*) and the effects of water temperature on the leaching process, *Korean J. Biologi. Sci,* **7**, 289-294 (**2003**)

20. Valiela I., Teal J.M., Allen S.D., Etten R.V., Goehringer D. and Volkmann S., Decomposition in salt marsh ecosystems: the phases and major factors affecting disappearance of above-ground organic matter, *Journal of Experimental Marine Biology and Ecology*, **89**, 29-54 (**1985**)

21. Mahmood H, Siddique MRH, Abdullah SMR, Saha S, Ghosh DC, Rahman MS, Limon SH. Nutrient dynamics associated with leaching and microbial decomposition of four abundant mangrove species leaf litter of the Sundarbans, Bangladesh, *Wetlands,* Doi-10.1007/s13157-013-0510-1, (**2013**)

22. Marschner H. Mineral nutrition of higher plants, Academic press, New York, USA, (**1995**)

23. Jones, J.B.Jr.. *Plant Nutrition Manual,* New York: CRC Press, (**1998**)

24. Semwal R.L., Maikhuri R.K., Rao K.S., Sen K.K., Saxena K.G., Leaf litter decomposition and nutrient release patterns of six multipurpose tree species of central Himalaya, India, *Bomass and Bioenergy,* **24**, 3-11 (**2003**)

25. BBS (Bangladesh Bureau of Statistics). *Statistical Pocket Book of Bangladesh,* Dhaka: Statistics Division. Ministry of Planning, (**2004**)

26. Kabir ME, Webb EL. Can homegardens conserve biodiversity in Bangladesh? *Biotropica*, **40**, 95–103, (**2008**)

27. Olson JS. Energy storage and the balance of producers and decomposers in ecological systems, *Ecology*, **44**, 322–331 (**1963**)

28. Allen S.E., Chemical analysis of ecological materials. Oxford: Blackwell Scientific Publications, (**1974**)

29. Mulvaney R.L., Nitrogen- Inorganic Forms, In Methods of Soil Analysis: Chemical Methods. Part 3. D.L. Sparks, editor. Soil Science Society of America, Madison, USA, 1123-1184 (**1996**)

30. Williams EG, Stewart AB. *J. Soc. Chem. Ind.* London, **60**, 291 **(1941)**

31. Weatherburm M.W., Phenol-hypochlorite reaction for determination of ammonia, *Analytical Chemistry,* **39**, 971-974 (**1967**)

32. Timothy R.P., Yoshiaki M. and Carol M.L., A manual of chemical and biological methods for seawater analysis, Oxford: Pergamon press, (**1984**)

33. Cundell A.M., Brown S.M., Stanford R. and Mitchell R., Microbial degradation of *Rhizophora mangle* leaves immersed in the sea, *Estuarine and Costal Marine Science,* **9**, 281-286 (**1979**)

34. Simlai A. and Roy A., Analysis of correlation between phytochemical and antimicrobial constituents of *Ceriops decandra*, a medicinal plant, from Indian Sundarban estuary, *Journal of Medicinal Plants Research,* **6**, 4755-4765 (**2012**)

35. Ibrahima A., Biyanzi P. and Halima M., Changes in organic compounds during leaf litter leaching: laboratory experiment on eight plant species of the Sudano-guinea of Ngaoundere, Cameroon, *Forest*, **1**, 27–33 (**2008**)

36. Ibrahima A., Gillon D. and Joffre R., Leaf litter decomposition of Mediterranean tree species in relation to temperature and initial water imbibitions under microcosm experiment, *Research Journal of Agriculture and Biological Sciences,* **6**, 32–39 (**2010**)

37. Mahmood H., Saberi O., Misri K. and Japar Sidik B., Nutrients dynamics associated with leaf litter degradation of *Bruguieria parviflora* (Whight and Arnold) at Kuala Selangor Mangrove forest, Malaysia, *Indian Journal of Forestry*, **30**, 325-330 (**2007**)

38. Bloomfield J., Vogt K.A. and Vogt D.J., Decay rate and substrate quality of fine roots and foliage of two tropical tree species in the Luquillo experimental forest, Puerto Rico, *Plant Soil*, **150**, 233−245 (**1993**)

39. Verhoef H.A. and Gunadi B., Decomposition dynamics and nutrient flow in pine forest plantation in Central Java. In: M.V. Reddy (ed.), *Management of Tropical Plantation-Forests and Their Soil Litter System*. Science Publisher, Inc., Enfield, NH, USA, 173−211 (**2001**)

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

41. Elevitch C. and Wilkinson K., Nitrogen fixing trees: Multipurpose pioneers, (**1998**)

42. Mahmood H. and Saberi O., Micro-nutrient contents of field grown seedlings, saplings and trees of a mangrove species, Bruguiera parviflora (Wight and Arnold) in the Kuala Selangor nature park, Malaysia, *Indian Forester,* **133**, 1057-1062 (**2007**)