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Litter Fall and Litter Dynamics in a Tropical Dry Deciduous Thorn Forest in Rajasthan in North-West India

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ABSTRACT

Litter fall and the dynamics of the forest litter was evaluated in a tropical dry deciduous thorn forest in Rajasthan (27° 4' to 28° 4' N and 76° 7' to 77° 13' E). The litter fall started in July, peaked in December (28 g m^{-2}) and declined to 12 g m^{-2} by January, and further to 1.8 g m^{-2} in May. Among the woody species, *Anogeissus pendula* exhibited highest leaf fall: 124, 12 and 22 g m^{-2} at the middle, base and top, respectively of a west-facing hill slope. The total annual litter production of woody vegetation was 2.03 Mg ha^{-1}; however, the maximum litter fall was 2.38 Mg ha^{-2} at the top of the hill slope. The total forest floor litter was 6 Mg ha^{-1} which consisted of 30, 59 and 11% of leaf litter, twig litter and miscellaneous litter respectively. The forest floor litter varied seasonally. The initial biomass of fresh litter (Fl), duff (D) and soil organic matter (SOM) was 1.6, 9.4 and 14.2 Mg ha^{-1} respectively. The loss of organic matter ranged from 72% in Fl to 53% in SOM component of the litter in one year. The decomposition of litter occurs mainly in the rainy season with 43% duff and 50% SOM disappearing in July-August, and about 47% each of duff and SOM biomass disappearing in December-January. Soil moisture and soil surface temperature played an important role in the decomposition of litter. Annual turnover rate of litter was 92% and turn over time was 1.07 years.

Key Words: Duff; Fresh litter; Forest floor litter; Litter fall; Soil organic matter.

INTRODUCTION

Litter fall is an important pathway for return of organic matter as well as nutrients from aerial parts of the plant community to the soil surface and it exerts a great influence on soil formation and fertility (Spain 1984). In forest ecosystems, nutrient dynamics is governed by patterns of litter fall, humification and decomposition, which differ from one forest type to the other (Olson 1963). The decomposition of plant litter is one of the crucial processes in the biogeochemical cycle of forest ecosystems (De Catanzaro and Kimminis 1985) and in the functioning of the soil-litter decomposer subsystem (Swift et al. 1975). Litter decomposition is regulated by an interplay of abiotic and substrate quality variables (Singh and Gupta 1977, Meentemeyer 1978, Swift et al. 1979, Mc Claugherty et al. 1985). The mechanism and controlling factors of litter decomposition in terrestrial habitats have been studied in wide variety of forest ecosystems under different climatic conditions (Singh and Gupta 1977, Swift et al. 1979, Anderson and Swift 1983, Xuluc-Tolosa et al 2003). In India, litter fall and litter decomposition have been evaluated in several tropical dry deciduous forests (Pandey et al. 1980, Singh and Singh 1981, Rout and Gupta 1989) but very little is known about it from the semiarid region of Rajasthan (Garg and Vyas 1975). The present study reports on the seasonal variation in litter fall and litter decomposition in a tropical dry deciduous thorn forest in Rajasthan.

THE STUDY SITE

The study was made in the Bala-fort reserve forest which is situated in the north-eastern part of Rajasthan in the Aravalli hills (27°4' to 28°4'N and 76°7' to 77°13' E). It lies about 4 km away from Alwar city and has a small fort, the Bala-fort, perched on the peak of a hill with west-facing slope. One of the unique features of this forest is that it is surrounded by about 2 m high wall since the establishment of Alwar state in 1775 AD (Mayaram 1968) and is, therefore, considered as the most protected forest area in this region. The undisturbed forest is surrounded by hills of uniform height (Mayaram 1968). The valley has an altitude of 480 m and the surrounding hills rise up to 570 m above sea level.

The forest is categorised as tropical dry deciduous thorn forest dominated by *Anogeissus pendula* (Yadav and Yadav 2005). The soil characteristics of the west facing hill slope are given in Table 1. The summers (March to June) are extremely hot with temperature soaring to 47°C. The rainy season, from July to mid September, experiences 90% of the 650mm annual rainfall (Figure 1). The dry cold winter season extends from October to February with temperature dropping to 4°C.

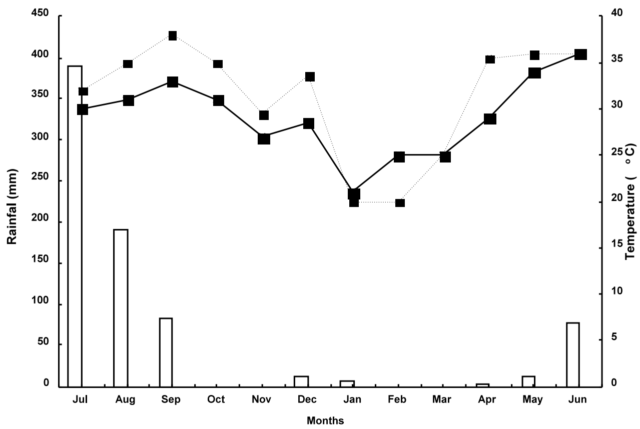

Figure 1. Average monthly rainfall ( ), Air temperature ( ) and Soil surface temperature ( ) from July 2003 to Jun 2004 of the Bala-fort forest.

Sampling Procedures

The litter fall was estimated using 10 litter traps, each 50 cm x 50 cm size with 15 cm high wooden frame and fitted with an iron net at the bottom and sides. The traps were placed randomly on the forest floor at the base, middle and top of the west facing hill slope. Litter accumulated in the traps was collected at monthly intervals from July 2002 to June 2003. The litter from each trap was placed in a paper bag separately and brought to the laboratory where the litter was separated species wise and that of the dominant tree *Anogeissus pendula* was separated into leaf, twig and miscellaneous components. Miscellaneous litter includes seeds, fruits and unidentified litter components.

The litter on the forest floor was also sampled by laying ten 50x50 cm quadrats randomly at the base, middle and top of the west facing hill at monthly intervals from February 2002 to January 2003. The litter was sorted out into three components (i) leaves (ii) twigs and (iii) miscellaneous litter. The litter fractions were dried at 80 ºC to a constant weight in hot air oven and weighed following Misra (1968). The location of sampling points was marked to avoid repeated collection from the same point.

Litter decomposition could not be evaluated by litter bag method as the litter bags were destroyed or removed by humans and wild herbivores in the forest. The litter decomposition was therefore examined under natural conditions. Litter was collected from 10 cm x 10 cm x 2 cm volume of soil along with all organic matter present on its surface, and five soil samples were taken at monthly intervals from 10 m x 10 m area fixed at three locations in the middle part of the west-facing hill slope.

Table 1 Soil characteristics of the west facing hill slope in the Bala-fort reserve forest.

Microhabitat	Soil texture	Soil depth (cm)	Soil pH	Conductivity (mS cm^{-1})	Organic carbon (%)	Soil moisture (%) Wet period	Soil moisture (%) Dry period
Top of slope	sandy loam	10± 0.2	7.6± 0.003	4.72 ± 0.1	1.06± 0.03	8.18	4.34
Middle of slope	sandy loam	10.7±0.2	7.4± 0.003	3.52 ± 0.1	1.12± 0.01	6.5	4.88
Base of slope	sandy loam	14.6±0.7	7.5± 0.003	3.33 ± 0.1	0.37± 0.01	6.15	3.1
Valley	sandy loam	>1m	7.4± 0.003	3.6 ± 0.1	0.72± 0.03	6.03	4.14

The litter samples were divided into four fractions: (i) fresh litter (ii) duff (iii) soil organic matter (SOM) which included humus and dead roots. The soil organic matter was obtained after mixing the soil in water and passing through a set of three sieves (2, 1.0 and 0.79 µm). The humus and fine root biomass fractions were referred to as soil organic matter (SOM). Fresh litter, duff and SOM were dried at 80 ºC to constant weight in a hot air oven and weighed. The decomposition rate of fresh litter, duff and SOM was deduced by dividing the loss of biomass in each fraction by initial biomass in the previous month. A diagrammatic model has been prepared by using the initial biomass, final mass and sum of monthly loss and gain of biomass in each fraction of litter. The air temperature (one m above soil surface) and soil surface temperature were recorded between 10 a.m. and 11 a.m. at monthly intervals in the middle part of the west-facing hill slope.

Data Analysis

Turnover rate (*k*) of litter of the forest floor was estimated by using mathematical model of Jenny et al. (1949) and Olson (1963) assuming that the forest floor was in a steady state condition (i.e., inputs = outputs)

$$K = A + F$$

where, K= Turnover rate; A = annual litter fall (calculated from input of fresh litter fall to forest floor); F = average ground litter. Turnover time (t) was calculated as reciprocal of turn over rate, i.e., $1/K$; where t = time (yr).

RESULTS

Litter Fall

The total annual litter production of shrubs and trees was 2.03 Mg ha^{-1} with 2.38,1.79 and 190 Mg ha^{-1} at the top, the middle and the base of the west-facing hill slope in the Bala-fort tropical dry deciduous thorn forest. The litter fall of most of the woody species occurred throughout the year with high fall from July to December. *Grewia flavescens* contributed maximum litter fall (91 g m^{-2}) followed by *Grewia tenax* (43 g m^{-2}), and *Anogeissus pendula* (22 g m^{-2}) at the top of the hill slope (Table 2). At the middle part of the slope, the maximum litter fall was contributed by *Anogeissus pendula* (124 g m^{-2}) followed by *Grewia flavescens* (15 g m^{-2}) (Table 3) whereas *Anogeissus pendula* (102 g m^{-2}) followed by *Wrightia tinctoria* (28 g m^{-2}) and *Grewia flavescens* (25 g m^{-2}) contributed at the base of the hill slope (Table 4).

Litterfall of *Anogeissus pendula*

The litter fall of *Anogeissus pendula* was evaluated because it is the dominant tree species in the hilly terrain of the tropical dry deciduous forests. Litter fall in *Anogeissus pendula* occurs over an extended phase from July to January and some litter fall also occurred in summer season (Table 5). In this species, highest litter fall occurred in July (27 g m^{-2}) at the base of the hill slope which comprised 8, 17 and 2 g m^{-2} leaf litter, twig litter and miscellaneous litter, respectively. The maximum leaf litter fall was in September which continues up to December but increased from January onwards at all the three micro-habitats. On the contrary, the twig litter fall was lowest in September to December but increased from January onwards to its peak in July. The miscellaneous litter fall occurred from October to March.

Forest Floor Litter

The forest floor litter was higher at the top of the hill slope than at the middle and the base of the slope (Table 6). At the top of the hill slope, the leaf litter biomass was lowest (153 g m^{-2}) in June, and then it increased from September onwards to attain peak value (270 g m^{-2}) in December. On the contrary, the lowest amount of twig litter was in February to May(241 g m^{-2}) which increased to 396 g m^{-2} in August whereas the miscellaneous litter was lowest in May (29 g m^{-2}) and highest in March (109 g m^{-2}). Similar trend was observed with respect to the different components of the forest floor litter at the middle and at the base of the hill slope in this forest.

Decomposition of Litter

The proportion of litter in different components in the initial standing crop was1.6 Mg ha $^{-1}$ in fresh litter,9.4 Mg ha-1 in duff and 14.2 Mg ha $^{-1}$ in the soil organic matter (SOM) (Table 7). It increased to 2.5 Mg ha^{-1} in fresh litter to 5.7 Mg ha^{-1} in duff and 16.4 Mg ha^{-1} in the SOM component at the end of one year period. Fresh litter was lowest in July-September and maximum in October-November and again in March-April. Duff was

Table 2. Monthly litter fall (g m^{-2}; ± S.E) of woody species on the top of west-facing hill slope in the Bala-fort forest

Species	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Acacia leucophloea	3.69±2.5	0.9±0.6	4.6±2.8	0.89±0.8	0.2 ±0.1	0.1± 0.1	2.8±1.7	—	1.3±1.3	—	—	—
Acacia senegal	—	—	1.1±0.7	—	—	0.24 ±0.1	0.4±0.3	0.74±0.5	1.8±0.2	0.1±0.1	—	—
Adhatoda zeylanica	0.19±0.1	0.5±0.3	0.5±0.2	0.92±0.9	9.06±2.7	4.54±1.4	0.4±0.3	1.24±0.6	3.1±1.2	0.9±0.4	—	—
Anogeissus pendula	3.5 ± 2.8	0.5±0.4	3.1±2.5	1.37±1.1	3.9 ±1.2	7.4 ± 1.9	0.4±0.4	4.41±1.8	0.3±0.2	—	—	—
Butea monosperma	—	—	—	—	—	3.21±1.5	—	—	2.8±1.7	4.3±2.2	1.6±1.0	1.7±1.1
Capparis sepiaria	0.55±0.5	0.8±0.6	—	—	—	—	0.1±0.1	0.98±0.5	0.1±0.1	—	0.2±0.1	0.1±0.1
Commiphora wightii	1.03±0.8	—	—	0.1±0.1	0.91±0.6	0.1± 0.1	0.5±0.5	—	—	—	0.3±0.1	—
Ehretia laevis	—	—	0.3±0.2	—	—	—	—	—	—	—	—	—
Grewia flavescens	17.9±8.1	4.4±1.3	6.5±1.8	23.6±10.4	1.19±0.8	16.3±1.9	4.5±0.7	13.6±2.8	2.9±1.2	—	0.2±0.1	—
Grewia tenax	10.5±4.1	2.5±0.6	5.7±0.9	2.69±0.6	16.9±1.6	1.95±0.8	0.3±0.1	0.91±0.8	1.0±0.9	—	—	0.2±0.1
Wrightia tinctoria	5.7±3.9	1.4±0.7	4.2±2.9	4.8±2.8	1.18±0.6	0.68±0.3	1.2±0.8	0.82±0.6	0.60.3	—	—	—
Total	42.84	11.07	25.76	34.38	33.34	34.49	10.48	22.7	13.69	5.25	2.25	2.05

Table 3. Monthly litter fall (g m^{-2}; ± S.E) of woody species on the middle of west-facing hill slope in the Bala-fort forest

Species	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Anogeissus pendula	16.2±3.22	6.6± 1.4	17.2±3.6	24.8± 2.3	23.6± 2.1	23.1±3.1	5.6±0.8	2.3±0.2	4.2±1.2	0.6±0.3	0.13±0.1	0.1±0.1
Acacia leucophloea	—	0.7± 0.4	1.68±1.1	0.51± 0.3	—	—	—	—	—	—	0.18±0.1	0.25±0.2
Acacia senegal	0.45±0.23	—	0.77±0.5	—	1.74± 0.9	1.24±0.5	0.7±0.4	—	0.3±0.1	0.3±0.2	0.1±0.1	—
Adhatoda zeylanica	1.07±0.3	5.1± 1.5	2.19±0.7	1.76± 0.4	1.24± 0.4	0.36±0.1	0.4±0.2	—	1.5±0.7	—	—	0.38±0.3
Butea monosperma	—	—	—	—	0.34± 0.3	—	—	0.9±0.6	0.1±0.1	—	0.64±0.4	0.61±0.4
Capparis sepiaria	1.13± 0.4	1.5± 0.6	0.26±0.1	0.24± 0.1	0.74± 0.4	0.95±0.5	2.1±1.2	0.5±0.2	1.1±0.1	0.1±0.1	0.16±0.1	0.61±0.4
Cordia dichotoma	—	—	—	0.94± 0.4	—	0.20±0.1	0.2±0.1	0.8±0.6	0.1±0.1	—	—	—
Ehretia laevis	—	—	—	—	0.28± 0.1	—	—	—	—	0.3±0.2	—	—
Grewia flavescens	0.65± 0.3	0.6± 0.1	0.41±0.1	3.82± 1.1	2.46± 0.9	1.64±0.6	1.5±0.3	0.5±0.2	2.5±1.1	0.4±0.3	—	0.1±0.1
Grewia tenax	0.40± 0.2	0.1± 0.1	0.51±0.2	0.13± 0.1	0.29± 0.2	0.17±0.1	0.1±0.1	0.1±0.1	—	0.4±0.2	0.11±0.1	0.28±0.1
Wrightia tinctoria	—	—	—	—	—	0.19±0.1	—	0.1±0.1	0.1±0.1	—	—	—
Total	19.94	14.64	22.98	32.17	30.17	27.78	10.58	5.27	9.82	2.14	1.27	2.23

Table 4. Monthly litter fall (g m^{-2}; ± S.E) of woody species on the base of west-facing hill slope in the Bala-fort forest

Species	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Anogeissus pendula	27.1± 8.9	6.5±1.5	15.7± 2.6	9.6±2.3	14.1±1.6	13.2± 0.7	5.2±1.7	1.7±0.8	4.8±1.1	3.7±1.2	0.1±0.1	0.19± 0.1
Acacia Senegal	0.23 ±0.2	—	—	—	0.2 ± 0.1	0.14± 0.1	—	—	0.1±0.1	—	0.3±0.2	0.1± 0.1
Adhatoda zeylanica	0.86 ±0.5	0.5±0.4	0.89± 0.6	0.3±0.2	1.89± 1.1	0.52± 0.2	0.2±0.2	0.3±0.2	2.4±1.1	1.0±0.5	0.1±0.1	0.16± 0.1
Butea monosperma	1.27 ±1.2	—	—	—	—	—	—	—	—	—	—	1.02± 0.6
Capparis sepiaria	0.18 ±0.2	—	—	0.1±0.1	0.24± 0.2	—	—	—	0.3±0.2	—	0.3±0.1	0.16± 0.1
Cordia dichotoma	0.44 ±0.3	1.6±1.4	0.1 ± 0.1	—	1.12± 0.4	1.15± 0.4	1.1±0.5	0.3±0.3	0.3±0.3	—	0.2±0.1	0.22± 0.1
Ehretia laevis	—	—	0.1 ± 0.1	0.2±0.1	0.33± 0.2	0.49± 0.3	—	1.6±1.1	—	8.5±7.7	0.8±0.5	1.1± 0.6
Grewia flavescens	0.90 ±0.6	3.2±1.1	1.98± 1.1	5.3±2.0	4.12± 2.2	4.04± 1.9	1.3±0.4	1.6±1.3	2.3±0.9	0.2±0.1	—	—
Grewia tenax	—	0.1±0.1	0.1 ± 0.1	—	0.13± 0.1	0.1 ± 0.1	—	—	—	—	—	—
Holoptelea integrifolia	—	—	—	—	—	0.38± 0.2	—	—	0.2±0.1	0.9±0.3	—	—
Lannea coromandelica	0.16 ±0.1	—	—	—	—	—	—	—	—	—	—	—
Wrightia tinctoria	4.66 ±4.4	2.1±2.1	6.2 ± 6.2	2.1±2.1	2.36± 1.5	2.65± 1.5	1.7±1.3	2.2±2.2	3.1±3.1	1.5±1.5	0.2±0.1	—
Total	35.84	13.97	24.89	17.52	24.5	22.59	9.5	7.62	13.46	15.74	1.9	2.95

Table 5. Seasonal pattern of litter fall (g m^{-2}; ± S.E) for *Anogeissus pendula* on the west-facing hill slope in the Bala-fort forest.

Months	Base			Middle			Top		
	Leaves	Twigs	Miscellaneous	Leaves	Twigs	Miscellaneous	Leaves	Twigs	Miscellaneous
Jul	7.83 ± 1.77	17.4 ± 9.24	1.91 ± 1.0	6.26 ± 1.07	9.11 ± 2.40	0.88 ± 0.36	1.30 ± 1.18	2.21 ± 1.67	—
Aug	5.41 ± 0.92	0.73 ± 0.29	0.58 ± 0.3	5.48 ± 1.01	1.12 ± 0.56	—	0.24 ± 0.24	0.09 ± 0.10	0.12 ± 0.07
Sept	15.5 ± 2.45	0.02 ± 0.02	0.14 ± 0.14	16.0 ± 3.38	1.24 ± 0.34	—	2.86 ± 2.34	0.17 ± 0.17	—
Oct	8.83 ± 2.25	0.40 ± 0.24	0.40 ± 0.24	19.4 ± 1.86	4.18 ± 0.96	1.17 ± 0.52	1.51 ± 1.02	0.05 ± 0.03	0.11 ± 0.06
Nov	10.9 ± 2.28	0.42 ± 0.12	2.99 ± 0.85	13.5 ± 1.29	3.96 ± 1.24	6.12 ± 0.91	1.01 ± 0.19	0.20 ± 0.10	2.69 ± 0.94
Dec	9.64 ± 1.09	0.10 ± 0.05	3.42 ± 0.94	10.6 ± 1.88	4.94 ± 0.48	7.61 ± 1.40	3.11 ± 0.99	2.11 ± 0.78	2.19 ± 0.63
Jan	3.98 ± 1.11	0.84 ± 0.59	0.34 ± 0.32	4.51 ± 0.65	0.76 ± 0.19	0.31 ± 0.11	0.26 ± 0.26	0.06 ± 0.06	0.07 ± 0.72
Feb	0.91 ± 0.33	0.54 ± 0.45	0.22 ± 0.01	1.96 ± 0.23	0.29 ± 0.11	0.06 ± 0.04	0.47 ± 0.47	0.54 ± 0.54	0.26 ± 0.26
Mar	0.51 ± 0.11	2.10 ± 1.05	2.06 ± 0.70	0.64 ± 0.17	1.99 ± 0.62	1.57 ± 0.53	—	0.26 ± 0.19	—
Apr	0.66 ± 0.18	3.02 ± 1.11	0.05 ± 0.05	0.15 ± 0.06	0.43 ± 0.17	0.04 ± 0.04	—	—	—
May	—	0.10 ± 0.11	—	0.02 ± 0.02	0.11 ± 0.09	—	—	—	—
Jun	—	0.19 ± 0.12	—	—	0.06 ± 0.03	—	—	—	—

Table 6. Variation in different components of forest floor litter (g m^{-2}; ± S.E) of the west-facing hill slope of the Bala-fort forest

Months	Base			Middle			Top		
	Leaves	Twigs	Miscellaneous	Leaves	Twigs	Miscellaneous	Leaves	Twigs	Miscellaneous
Feb- 02	245.6± 9.8	241.1± 12.9	74.05±4.54	164.5±26.7	284.2±38.7	63.01±8.04	215.7±26.9	247.6± 56.5	46.3 ± 14.9
Mar –02	241.4±28.6	418.2± 63.1	109.3±44.6	190.0 ± 6.4	257.1±37.5	104.7±31.5	201.5±25.1	220.0 ±58.3	36.97±13.4
Apr – 02	231.5 ± 2.0	303.4± 13.8	53.54± 4.2	130.2± 5.8	364.8±45.5	61.9 ± 8.3	168.2 ± 7.3	248.7±52.8	28.9 ± 3.5
May- 02	220.4±26.2	372.2± 29.3	29.2 ±10.9	163.3±15.6	389.4± 29	61.56±21.6	170.1±10.3	334.9±35.5	36.9 ± 4.7
June-02	152.8±25.9	471.6± 74.2	83.4 ±22.4	137.4±18.1	538.1±74.3	52.1 ±14.1	92.98 ± 3.7	409.4±35.6	88.2 ±36.7
July- 02	155.3±18.4	292.4± 50.6	101.3± 6.7	51.4 ±12.4	353.5± 9.5	62.9 ± 8.2	82.5 ± 17.9	295.8±20.7	61.9 ± 7.1
Aug- 02	165.4± 20.5	396.4± 22.9	78.7± 7.70	57.8 ± 5.7	322.4±19.3	79.2 ±3.99	43.9 ± 2.99	411.0± 88.6	47.4 ± 15.6
Sept-02	183.9± 38.1	369.1± 43.4	67.4±11.7	153.2±31.3	368.3±33.6	63.14±15.3	136.5±11.1	346.7±18.6	14.8 ± 2.97
Oct- 02	231.1± 3.70	327.8± 27.2	101.2±6.5	117.2±11.7	334.3±32.5	39.27± 8.4	185.9±20.9	411.2±34.9	78.3 ± 28.7
Nov-02	239.4 ± 7.0	305.1± 25.1	86.3±3.49	140.0 ± 7.1	310.2±15.9	52.1 ± 3.6	163.2 ±23.0	321.5±54.6	48.6 ± 7.7
Dec-02	270.0 ±13.0	282.3± 18.3	75.6 ± 4.7	189.4±12.6	298.3±10.7	68.8 ± 6.2	236.2 ± 5.7	357.1±41.1	50.1 ± 5.2
Jan- 03	254.9±38.2	262.5± 28.2	73.8 ± 6.9	187.9±21.6	288.8±25.0	66.0 ± 7.4	193.9 ± 8.4	315 ± 16.2	16.5 ± 4.6

lowest in August-October and maximum in November-December and in March. SOM was lowest in August-September and remained high throughout the remaining part of the year with peak values in November and June. The initial and final standing crops from July 2003 and June 2004 are same (25 Mg ha^{-1}), and the annual gain and loss of litter biomass during the same period are 44.85 Mg $ha^{-1}$and 45.42 Mg ha^{-1} respectively (Figure 2). Hence the annual flux in the standing crop of litter suggests that the litter dynamics of the west-facing slope is in a steady state condition. This means the loss of dead organic matter is mainly through decomposition. The decomposition of litter is highest in July- August when it is 43% for duff and 50% for SOM (Figure 3). In summer, it was 40% for both duff and SOM in April. In winter season, the decomposition of litter occurs slowly with 47% for duff and below 20% for SOM in December-January.

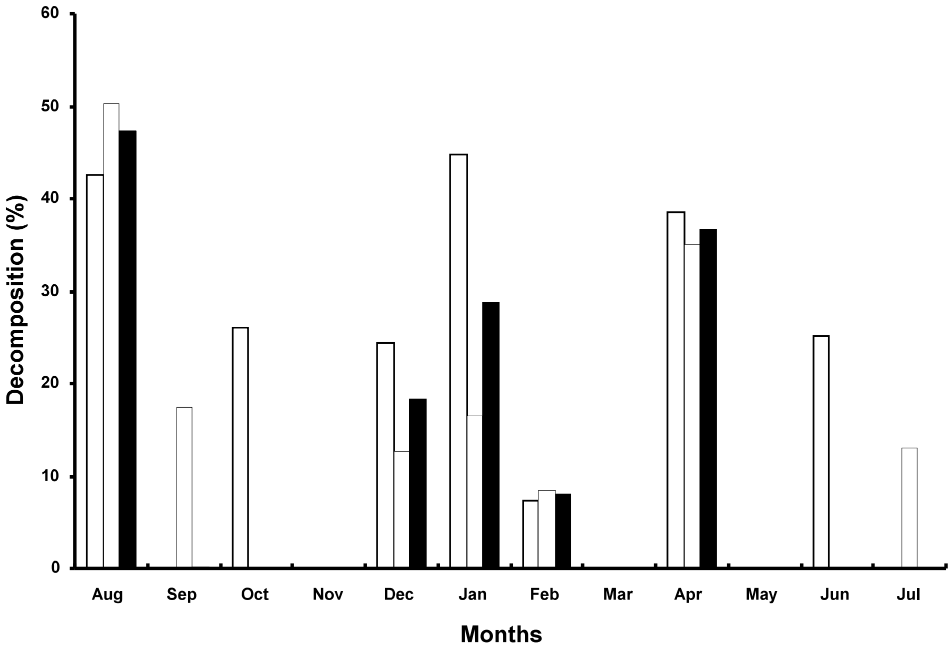

Figure 2. Decomposition rate of duff ( ), soil organic matter ( ) and of both litter components considered together ( ) in the west facing slope of the Bala-fort reserve forest

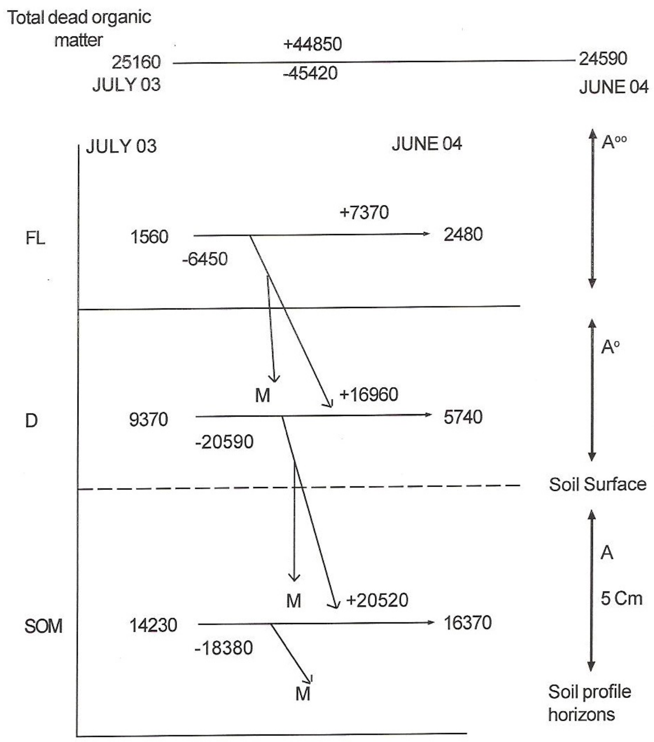

Figure 3. Outline diagram of litter dynamics on a west-facing hill slope in the Bala-fort forest; FL= fresh litter, D= duff, SOM = soil organic matter and M = mineralization (kg ha^{-1}).

Table 7. Dry weight of various components of litter (Mg ha^{-1}) on monthly basis on the west facing hill slope in the Bala-fort forest (± S.E).

Months	Fresh Litter	Duff	SOM
July-03	1.56 ± 0.32	9.37 ± 2.15	14.23 ± 4.25
Aug-03	1.74 ± 0.28	5.38 ± 0.74	7.07 ± 1.21
Sept-03	1.63 ± 0.06	5.71 ± 1.30	5.84 ± 0.48
Oct-03	5.46 ± 0.99	4.22 ± 0.35	11.54 ± 2.83
Nov-03	4.69 ± 0.52	14.99 ± 2.96	16.83 ± 2.94
Dec-03	3.67 ± 0.41	11.32 ± 0.48	14.69 ± 1.84
Jan-04	2.78 ± 0.38	6.25 ± 0.84	12.26 ± 1.82
Feb-04	2.96 ± 0.33	5.79 ± 1.57	11.23 ± 1.67
Mar-04	4.81 ± 0.66	10.34 ± 1.01	12.54 ± 3.15
Apr-04	6.14 ± 0.92	6.35 ± 0.97	8.15 ± 0.84
May-04	3.68 ± 1.12	7.66 ± 0.53	13.05 ± 1.14
Jun-04	2.48 ± 0.36	5.74 ± 0.60	2.3

DISCUSSION

Litterfall

Mean annual litter production was 2.03 Mg ha^{-1} in the Bala-fort tropical dry deciduous thorn forest, which is within the range of 1.7 to 2.1 Mg ha^{-1} yr^{-1} litter in the tropical dry deciduous forest at Varanasi (Gaur and Pandey 1978, Pandey et al. 1980). However, it is very low as compared to 10.45 Mg ha^{-1} in dry deciduous forest of Morni hills in western Himalayas (Gupta and Rout 1992). Bray and Gorham (1964) and O'Neill and De Angelis (1980) have given the annual litter fall range between 1.0 - 3.3 Mg ha^{-1} in Arctic,3.5 0 4.6 Mg ha^{-1} in cool temperate,4.7 - 5.5 Mg ha^{-1} in warm temperate and 9.3 - 10.9 Mg ha^{-1} in equatorial forests. Indian dry forests lie between the warm temperate to equatorial forests (Singh et al. 1992). Murphy and Lugo (1986) also suggested that the annual litter fall of dry tropical forests of the world is between 3 and 10 Mg ha^{-1}. However, the annual litterfall of this tropical dry deciduous thorn forest is quite low. The low value of annual litter production in the Bala-fort forest may be attributed to severe drought conditions for nine months in a year.

The uniform temporal pattern of litter production at the base, middle and top of the hill slope indicates that the climatic regime acts uniformly on the vegetation of the three micro-habitats. Hence the difference in the litter production of these micro-habitats may be related to species composition of the vegetation. The dominance of *Anogeissus pendula* in the middle part of the slope, suppresses the growth of shrubs such as *Grewia flavescens* and *Adhatoda zeylanica,* which contribute greatly to the litterfall at the base and at the top of the slope. The litter production was a continuous process in this forest with a peak during September to December. The leaf fall is mainly caused by decrease in soil moisture and temperature in that period (Yadav and Yadav (2008). Singh et al. (1992) reported that the litterfall occurred throughout the year with peak fall from November to January. However, in our study, the peak advanced by two months, i.e. from September onwards which may be due to decline in soil moisture with the early retreat of monsoon. The relationship between rainfall and litter fall has been suggested by Graciela - Sanchez and Alvarez - Sanchez (1995) and Alvarez-Sanchez and Guevara (1993). Several workers have observed that the dry season favored higher litter production (Bernhard 1970, Haines and Folster 1977, Kira 1978, Kunkel-Westphal and Kunkel 1979, Spain 1984, Roy et al. 2005). The litter fall may also be caused by other factors such as high winds, soil characteristics and minerals deficiency (John 1973, Duvigneau 1976). The continuous litter fall from July to April may also be due to extended leaf fall in *Anogeissus pendula* and *Wrightia tinctoria* that mainly contributed to the annual litter in this forest. In the deciduous forest at the Morni hills, Gupta and Rawat (1992) also observed that *Anogeissus pendula* exhibited leaf fall throughout the year except in May.

Litterfall of *Anogeissus pendula*

Out of the total litter fall of *Anogeissus pendula* the leaf litter, twig litter and miscellaneous (flower and fruit) litter was 63, 25 and 12% respectively (Table 5).This is in agreement with Jordan (1983) who suggested that leaf litter production is higher and twig litter production is lower in tropics as compared to temperate forests. Thus the maintenance cost of the photosynthetic system is much higher in tropics, which is compensated with a decrease in wood production and as increased photo-synthetic biomass (Medina and Klinge 1983). However, at the top of the slope, leaf litter was 49 percent and the miscellaneous (flower and fruit) litter was 25 percent. This indicates that *Anogeissus pendula* allocates more resources to reproductive structures in adverse conditions like the pioneer species. Its dominance of vegetation from early secondary succession stages to the climax vegetation further supports this view point.

Forest Floor Litter

The total annual forest floor litter is almost equal to 6.1 Mg ha^{-1} reported for a tropical dry deciduous forest at Morni hills in Western Himalayas (Gupta and Rout 1992) but within the range of dry deciduous forest (Singh and Misra 1979, Murphy and Lugo 1986). However, the contribution of leaf litter and twig litter was 30% and 38% respectively at the Morni hills forest. There was a higher percentage of twig litter in the Bala-fort forest as compared to the Morni hills forest. The lower percentage of leaf litter in the forest floor litter of the Bala-fort forest suggests that it may be due to the faster decomposition of leaf litter as compared to the other components of litter. The effect of micro-habitat on the litter production in the forest was quite distinct. The forest floor litter biomass decreased with increase in height of the west facing hill slope in the Bala-fort forest (Table 6). The maximum forest floor litter was recorded in December which may be due to heavy litter fall from October - December whereas the lowest ground litter in July- August may be due to high decomposition rates of litter in rainy season. Twig litter (70%) was highest in the month of June, which may be attributed partly to its slow decomposition rate because of high temperature and partly to relatively high fall of twigs due to strong winds in this season.

There is a close relationship between seasonal variation in litter standing crop with the seasonality of litter fall and nature of climatic conditions prevailing in the study site. During the winter the highest monthly litter fall coincides with the maximum monthly accumulation of litter standing crop in the forest. This may be due to high litter fall and reduced rate of litter decomposition during this period, which results in accumulation of litter on the forest floor. Forest floor litter was highest at the top of the hill slope, constituting 37% of annual litter biomass, which gradually decreased towards the base of west facing hill slope.

The annual turnover rate of litter in the Bala-fort tropical dry deciduous thorn forest is 0.92 (Table 8). This is in conformity with the turnover rate of litter (0.96) observed for dry deciduous forest at Varanasi (Singh and Singh 1989). The turn over time was 1.07 years for the forest floor litter of this forest. The less turn over time of litter decomposition as compared to mixed deciduous forests (1.3 yr) indicates that forest floor of the present study site is more dynamic in nature.

Table 8. Annual turnover rate of forest floor litter on the west-facing hill slope in the Bala-fort reserve forest.

Litter component	Turnover rate (yr^{-1}) Base	Middle	Top	Slope	Turnover time (yr)
Leaf litter	0.91	0.90	0.91	0.91	1.09
Twig litter	0.93	0.93	0.94	0.93	1.07
Miscellaneous	0.97	0.92	0.93	0.94	1.06
Total 0.92	0.92	0.93	0.93	1.07	

Decomposition of Litter

When the decomposition of both duff and SOM considered together, its peak was in rainy season (July - August) and in winter (December – January), although it was highest in the rainy season (Figure 2). The loss of organic matter at each component level may be due to mineralization or transfer of partially decomposed organic matter to the next component. The organic matter decreases from (72%) in fresh litter to 53% in SOM component. The decomposition of duff and SOM occurred throughout the year with higher decomposition rate of the former in the month of August and again in January and that of latter in August and April (Figure 2). This indicates that the high soil surface temperature as compared to air temperature in these months favor decomposition of duff whereas the low temperature below soil surface in winter decreases the disappearance of SOM. However, the higher soil surface temperature (38°C) in September as compared to August adversely affects the decomposition of duff (Figure1.). Besides temperature winter showers also play important role in litter decomposition. Gupta and Singh (1981) suggested that the combined effect of temperature and moisture is more prominent on litter decomposition than the effect of temperature alone. The decomposition rate of duff remained above 25 percent whereas that of SOM remained less than 20 percent throughout the year (Figure 3). This suggested that duff is decomposed at faster rate than the soil organic matter (SOM). These observations indicate that decomposition occurred mainly in the rainy season and at a slower rate in winter (December- January).

The pattern of annual rainfall and the monthly decomposition rates of litter suggest that decomposition of litter is directly related to rainfall and soil surface temperature (Figure 1). This is in agreement with Singh (1978), Singh and Misra (1979) and Datta Munshi et al. (1987), who observed that fast disappearance rate of litter during rainy season might be due to accelerated growth of microbial population and their activities to decompose the litter in the presence of sufficient moisture and optimum temperature, while it was moderate in the winter season and at a slow rate in the summer season. Similarly Okeke and Omaliko(1992) reported that rainfall had a major impact over the decomposition rate. These observations are also in agreement with that of Bernhard (1970) who reported maximum decomposition rates during rainy season in the evergreen forests of Ivory Coast. High litter decomposition rates during the monsoon season have been observed (Rajvanshi and Gupta 1986, Khiewtam and Ramakrishnan 1993). Rainfall and temperature play important role in decomposition of litter in forest ecosystems (Upadhyay and Singh 1989, Upadhyay et al. 1989, Sandhu et al.1990). Monthly rainfall is a more important factor in regulating weight loss of litter than is temperature (Upadhyay *et. al.*1989). The observations exhibited that high rate of decomposition of litter also occurs in winter season (December-January). This is in conformity with Black (1970) also reported considerable amount of litter decomposition in winter months. The data collected for air and soil surface temperature and the monthly rain fall during the experimental period (Figure 1) of the study site showed that high soil surface temperature along with rain fall in December enhances the process of decomposition of litter in this dry deciduous forest.

CONCLUSIONS

The summarization of the data of standing crop, and gain and loss of organic matter to different components of litter in a year exhibited that there was a gradual increase in the standing crop of organic matter from fresh litter to SOM. The disappearance of organic matter was highest in duff followed by SOM component. Thus almost 50% of organic matter of the standing crop of litter was present in the SOM component. It may be inferred that large amount of organic matter is always present in the soil of this tropical dry deciduous forest. Hence, this forest ecosystem may represent a sub-climax stage with respect to litter dynamics.

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