Annals of Arid Zone 53(3&4): 169-176, 2014

Production and Decomposition of Litter in *Prosopis cineraria* Plantation Along Canal Banks in Indian Desert

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Abstract: Temporal dynamics of litter production and it's decomposition in *Prosopis cineraria* plantation in IGNP command area has been studied. Annual litter production varied greatly with plantation age and stem density in *P. cineraria* being high in 17-year-old plantation (1240 kg ha^{-1}). Lowest litter production was recorded in 4-year-old plantation (384 kg ha^{-1}). Because of the prevailing climate in the area litter-fall is seen throughout the year. Lot of seasonal variation was observed in plantations of different age classes. Bimodal pattern of litter fall was observed where two peaks of varied intensity were recorded in summer and winter. Overall, litter production was more in winter months except Y11 plantation. Component wise, leaf litter accounted for the major part of the total litter production. It varied from 63% in 11-year-old plantations to 75% in 17-year-old plantations. Woody litter component varied from 25% to 37% in plantations of different age. Value of decomposition constant (k) was 0.7339, signifying moderate rate of decomposition. A significant positive relationship between annual total litter production and girth at breast height (GBH) as well as tree height was observed. Moderate rate of decomposition signified moderate rate of nutrient turnover in *P. cineraria* plantations.

Key words: Litter, *Prosopis cineraria*, decomposition, arid zone, plantation.

A phenomenal change in the land use scenario has taken place with the advent of canal irrigation through Indira Gandhi Nahar Pariyojna (IGNP) in hot arid ecosystem of northwestern Rajasthan (Ram and Chauhan, 2002). Afforestation on large scale was taken up in the project area to protect the canal systems from drifting sand (GoR, 2002). As envisaged, these plantations have brought about a radical change in the landscape and microclimate in the area. Establishment of new plantations provides an opportunity to improve vital ecosystem services such as: litter supply, nutrient cycling, water infiltration, control of erosion etc. (León and Osorio, 2014). A vital role of ecosystem function is the continuous flow of nutrients and energy through various components of ecosystem. Litterfall and litter decomposition represent a large and dynamic portion of the nutrient cycling in a forest ecosystem (Bray and Gorham, 1964; Kim *et al*., 2003; You *et al*., 2000; Khiewtam and Ramakrishnan, 1993) and transfer of nutrients from aboveground vegetation to soil (Berg and McClaugherty, 2014; Vitousek, 1982; Vitousek and Sanford, 1986). Significant amounts of organic matter and nutrients in the soils can be transferred during litter decomposition processes (Lisanework and Michelsen, 1994).

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Litterfall is a major component of net primary productivity also and may provide important information as a phenological indicator of climate change effects on forests (Hansen *et al*., 2009). Many authors used litterfall as an index of NPP considering that annual leaf fall represents one-third of total Annual NPP (Bray and Gorham, 1964).

Several factors affect the litter-fall in plantation forests. Important among those are climate, latitude and altitude, site quality, tree species and stem density. Plenty of literatures are available with reference to the effect of these factors on litter production in tropical forest (Singh and Joshi, 1982; Proctor *et al*., 1983; Bhat, 1990; Gupta and Rout, 1992; Khiewtam and Ramakrishnan, 1993; Jana, 1998; Pandit and Jana, 2000) but in the context of arid conditions like western Rajasthan very few references are available. Therefore, knowledge of litter and nutrient dynamics in the canal side plantation ecosystem is required for its sustainable management. This will broaden our understanding of the ecology of tree plantation and to provide ecologically sound criteria for selection and management of plantation in Indian desert. We have focused on temporal dynamics of litter production and it's decomposition in *Prosopis cineraria* (the state tree of Rajasthan) plantation in IGNP command area.

Materials and Methods

Study site

The study was carried out in Stage–II of Indira Gandhi Nahar Pariyojana (IGNP) covering Nachna and Ramgarh Tehsil of Jaisalmer district (26°4′-28°23′ north latitude and 69°20′-72°42′ east longitude). The climate of Jaisalmer is very hot and dry in the summer season (GoI, 1991). Lasting from April to October, summers experience an average temperature in the range of the 41.6°C (max.) to 25°C (min.), maximum temperature reaching up to 49.2°C. The climatic conditions in winters are windy and chilly. The average temperature varies between 23.6°C (max.) to 7.9°C (min) with lowest temperature in the range of 1°C. Annual average rainfall of Jaisalmer is 164 mm.

Sampling design and sample collection

Quadrates of 10 m x 10 m size were randomly marked in plantations of *P. cineraria* in 2003 (Table 1). There were four replications in each of the four age classes (4, 8, 11 and 17 year old). All the quadrates were initially cleared and swept of any deposited debris. To provide firmness to the soil surface a layer of mud slurry was spread all over the plots. Monthly estimation of litter fall was made by collecting the litter from these quadrates and then sorting into leaves, twigs/branches, barks and flower/fruits for two years. Samples of these litter fractions were collected and brought to the laboratory for determination of oven dry weight at 80°C from each quadrate.

Litter decomposition

Litter decomposition was investigated by litter bag method (Singh *et al*., 1993). Twenty four litter bags were placed in each quadrate and were retrieved at monthly intervals. All the samples were brought to the laboratory in polythene bags and made them free from the foreign materials. The fresh and dry weight of the samples was determined. The decomposition constant (k) was calculated using the model of Olson (1963):

$$X/Xo = e^{-k}$$

where, X is the weight remaining at the end of one year, Xo is the original weight in bag and e is the base of natural log.

Statistical analysis

To assess the relation between growth parameters (girth at breast height and tree height) and annual litter production, correlation test was carried out using SPSS package. Equations were also developed on the basis of the best fit model using linear and non linear models to estimate annual litter production on the basis of plantation age, height and girth at breast height (GBH). On-way ANOVA was conducted to study the effect of age on different components to litterfall.

Results and Discussion

Litter production

Highest litter production was observed in 17-year-old (Y17) plantation (1240 kg $ha^{-1}y^{-1}$) followed by 8-year-old (Y8) plantation (749 kg ha^{-1} y^{-1}), 11-year-old (Y11) plantation (548 kg ha^{-1} y^{-1}) and 4-year-old (Y4) plantation (384 kg ha^{-1}). Component wise litter production in different age classes is presented in Table 2. With increase in plantation age significantly (P<0.001) higher litter-fall was recorded in *P. cineraria*. However, in Y11 plantation low litter-fall was observed in comparison to Y8. Total litter-production in Y17 plantation was much higher in comparison to other age

Table 1. Location of plots, number of stems and average growth parameters of Prosopis cineraria tree

Replication	4-year-old (1999) 300 RD, SMGS			8-year-old (1994, CSP) 7.5 RD Sada			11-year-old (1992) 1235 RD			17-year-old (1986) Nachna		
	Stems/ plot	CG (cm)	Height (m)	Stems/ plot	GBH (cm)	Height (m)	Stems/ plot	GBH (cm)	Height (m)	Stems/ plot	GBH (cm)	Height (m)
R1	14	19.64	3.46	16	18.12	4.23	25	25.89	5.15	8	51.63	6.71
R2	16	18.65	3.36	16	29.55	5.17	8	57.09	7.15	6	51.16	6.08
R3	16	18.50	3.85	16	37.0	5.45	9	44.49	6.17	10	51.70	8.00
R4	16	18.50	3.45	16	36.89	6.32	16	35.8	6.35	16	65.5	10.4
Mean	15.5	18.82	3.53	16	30.40	5.29	14.5	40.82	6.20	8.75	54.99	7.80

CG: Collar girth; GBH: Girth at breast height; SMGS: Sagarmal Gopa Shakha; CSP: Canal Side Plantation

Table 2. Component wise mean and standard deviation of annual litter production (kg ha^{-1}) in Prosopis cineraria plantation

Age class	Leaf litter	Woody litter	Total litter
Y4	$257^a \pm 27$	$127^a \pm 11$	$384^a \pm 32$
Y8	$532^c \pm 57$	$217^b \pm 25$	$749^c \pm 40$
Y11	$345^b \pm 44$	$203^b \pm 5$	$548^b \pm 40$
Y17	$927^d \pm 17$	$313^c \pm 20$	$1240^d \pm 18$

Values with the same superscript letter within a row are not significantly different

classes; almost triple than Y4 and double than Y11 plantations. Low litter production in Y11 plantation in comparison to Y8 plantation might be because of poor growth and stand density (Table 1) similar to the observation of Singh *et al.* (1993).

We obtained a significant relationship between annual total litter production and age of plantation ($r^2 = 0.813$, P<0.01), GBH ($r^2 = 0.72$, P<0.01) as well as tree height ($r^2 = 0.70$, P<0.01) in the study. GBH for plants of Y4 stands was taken as 68% of the collar girth of respective plants (we arrived at the figure after recording collar girth and GBH of 50 *P. cineraria* plants of same age). It shows the positive impact of age and growth on litter production. Annual litter production (ALP) was modeled against plantation age, height and GBH using linear and non-linear procedures. It was observed that nonlinear fitting produced better result than linear models. The precise and best model for litter production estimation (Fig. 1) against plant height is as follows.

$$ALP = 117.464588 * height^{1.01019}$$

$$(R^2 = 0.512,\ MSE = 0.1109462,\ F = 14.6681)$$

The best model fitting for estimation of litter production against GBH is

$$ALP = 94.943402 * GBH^{0.565494}$$

$$(R^2 = 0.538,\ MSE = 0.1048585,\ F = 16.332)$$

It is evident from the equations that GBH (Girth at breast height) is better in estimating the litterfall in *P. cineraria*. Moreover, GBH can be easily and accurately measured in the field as compared to the tree height.

Litter dynamics

Because of the prevailing climate in the area litter-fall is seen throughout the year. However, intensity of litter-fall increased at the end of dry season. Lot of seasonal variation was observed in plantations of different age classes. In Y17 plantation maximum litter-fall was recorded in winter season when 58% of total litter-fall was received from December to March. In February alone 21% of the total litter-fall occurred. Two maxima were observed in February and June (contributing 37% of total litter-fall). Two minima were in the months of April (growing season) and September (least stress period). In Y11 plantation, 59% of the total litter-fall was recorded during summer (April to June) in which June alone contributed 36% of the total litter-fall. In winter months (December to February) 27% of the total litter-fall was recorded. In Y8 plantation, winter months (December to February) produced maximum (47%) litter. About 46% total litter production in Y4 plantation, was observed during December to February whereas, during June to August 33% of total litter-fall was recorded.

Leaf litter

Leaf litter production followed more or less the same trend as in case of total litter. A bimodal pattern of leaf litter-fall was observed in all the age classes though period of high leaf litter-fall varied. Maximum leaf litter in Y17 plantations was produced in winter which extended up to March. During December to March 69% of annual leaf litter-fall was recorded with 27% in the month of February alone. A small and short peak was also observed during May-June, when 15% of annual leaf litter-fall was recorded. In Y11 plantation winter fall lasted up to February and the period from December to February produced relatively low quantity (30% of annual leaf litter) of leaf litter as compared to summer fall. During April to June 55% of the annual leaf litter-fall was observed. Summer peak was observed in June contributing 25% of the annual leaf litter production. Like Y17 plantation maximum leaf litter production in Y8 and Y4 plantation was also recorded in winter from December to February when 47% and 46% of the annual leaf litter was produced respectively. Second peak, though short and low in magnitude, was observed during September-October and July-August in Y8 and Y4 plantations respectively when 23% of annual leaf litter-fall occurred.

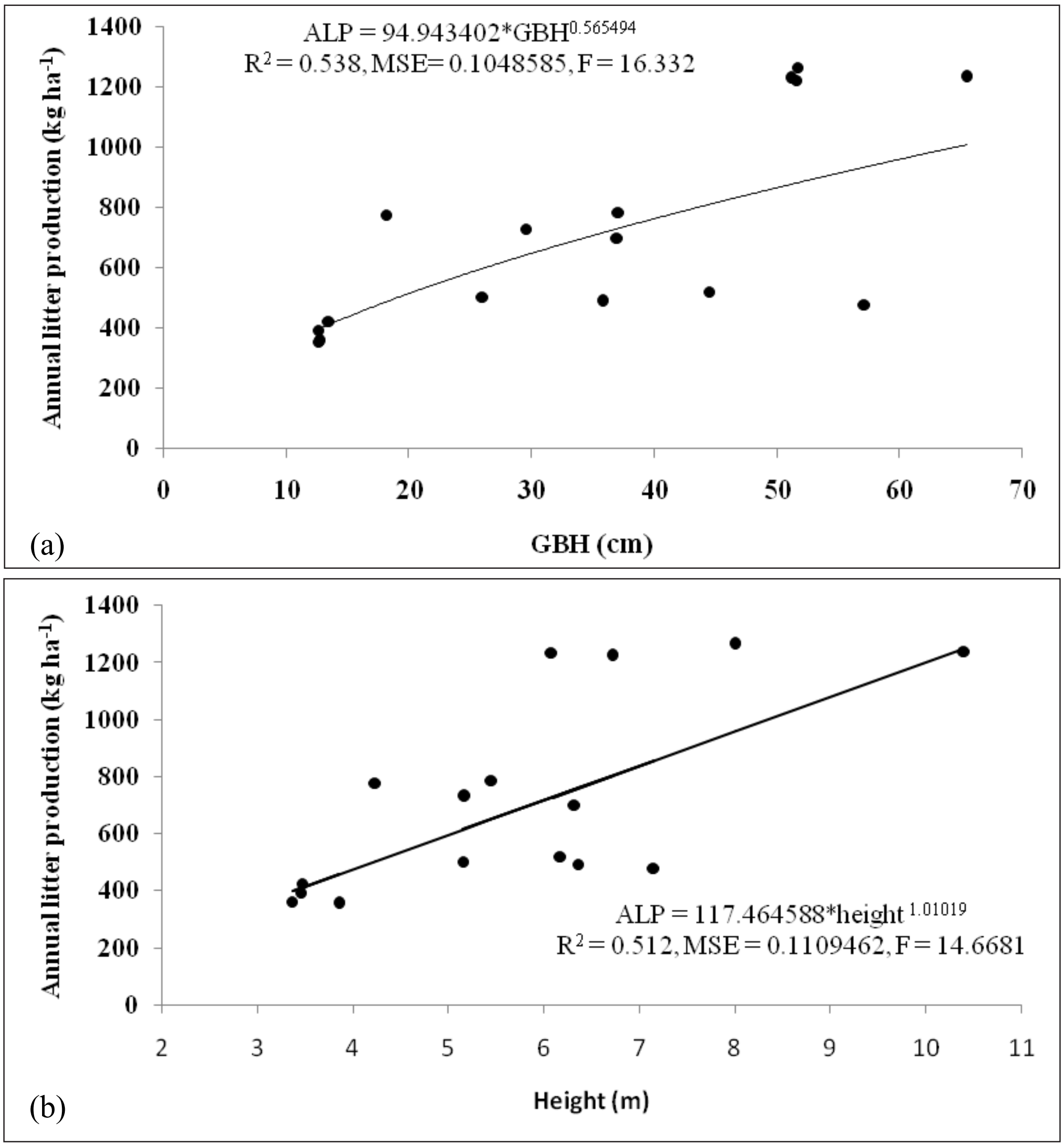


Fig. 1. Best model for litter production estimation against (a) GBH and (b) height.

Woody litter

Significant seasonal variation was observed in woody litter production in different age classes at *P. cineraria*. In older plantations (i.e. Y17 and Y11) maximum woody litter production was recorded in summer. In Y17 plantation 62% of annual woody litter-fall was observed in dry summer months with a peak in June contributing 36% of woody litter-fall. Very low and short peak was also observed in December when 15% of the annual woody litter was produced. In Y11 plantation both the peaks were very short. In the month of June 55% of the annual woody litter-fall was observed while during December-January it was only 18%. In Y8 plantation November to January was the period of maximum (63%) woody litter-fall. Not much of this was observed during summer. Woody litter-fall in Y4 plantation was well distributed in summer and winter season contributing 25% and 28% of annual woody litter, respectively. Overall, the period between February and May has seen least woody litter-fall.

Contribution of different litter components to total litter is shown in Figure 2. In all the age classes leaf litter contributes the major share. Contribution of leaf litter was highest (75%) in Y17 plantation followed by Y8 (71%), Y4 (67%) and Y11 (63%). This value compares well

Table 3. Decomposition constant and time required to reach half decay in different species

Species	% of original weight remaining	Decomposition constant (K)	t (years) (Half time)
Prosopis cineraria	48	0.7339	0.94

with other studies conducted elsewhere (Bray and Gorham, 1964; Singh, 1992; Yadav *et al.*, 2008; Pragasan and Parthasarathy, 2005; Londe *et al.*, 2016). Mehra *et al.* (1985) observed that tree leaf litter accounted for 54% to 82% of total litter-fall in six Central Himalayan forest ecosystems in India. It is observed that in old plantation relative contribution of leaf litter is more in comparison to young plantation. High woody litter component (37%) was observed in Y11 plantation. This may be attributed to poor site quality and stress condition in those plots, which produced more dry branches/twigs.

However, there are very few studies related to litter production in *P. cineraria* plantation in hot arid region and literature are not available for comparison with the present investigation. Most of the studies on litter fall are made in natural forest ecosystems or in agroforestry (Yadav *et al*., 2008). So it is very difficult to relate the findings of the present study to those in other ecosystems. Yadav *et al*. (2008) reported 1325 kg ha^{-1} $year^{-1}$ litter production by *P. cineraria* in agroforestry system (26 trees ha^{-1}) with 531 mm mean annual rainfall (semi arid region). This is comparable with the finding of the present study in spite of variation in stem density and climate. On the other hand report of 3437.5 kg ha^{-1} $year^{-1}$ litter production in *A. nilotica* plantation on alkali soils at CSSRI, Karnal, India (Kaur, 1998) and 6087 kg ha^{-1} $year^{-1}$ litter production by *E. camaldulensis* plantation in IGNP area (Bala *et al*., 2010) is on much higher side. Litter production in some forests/plantations/agroforestry systems of dry tropics are given in Table 4.

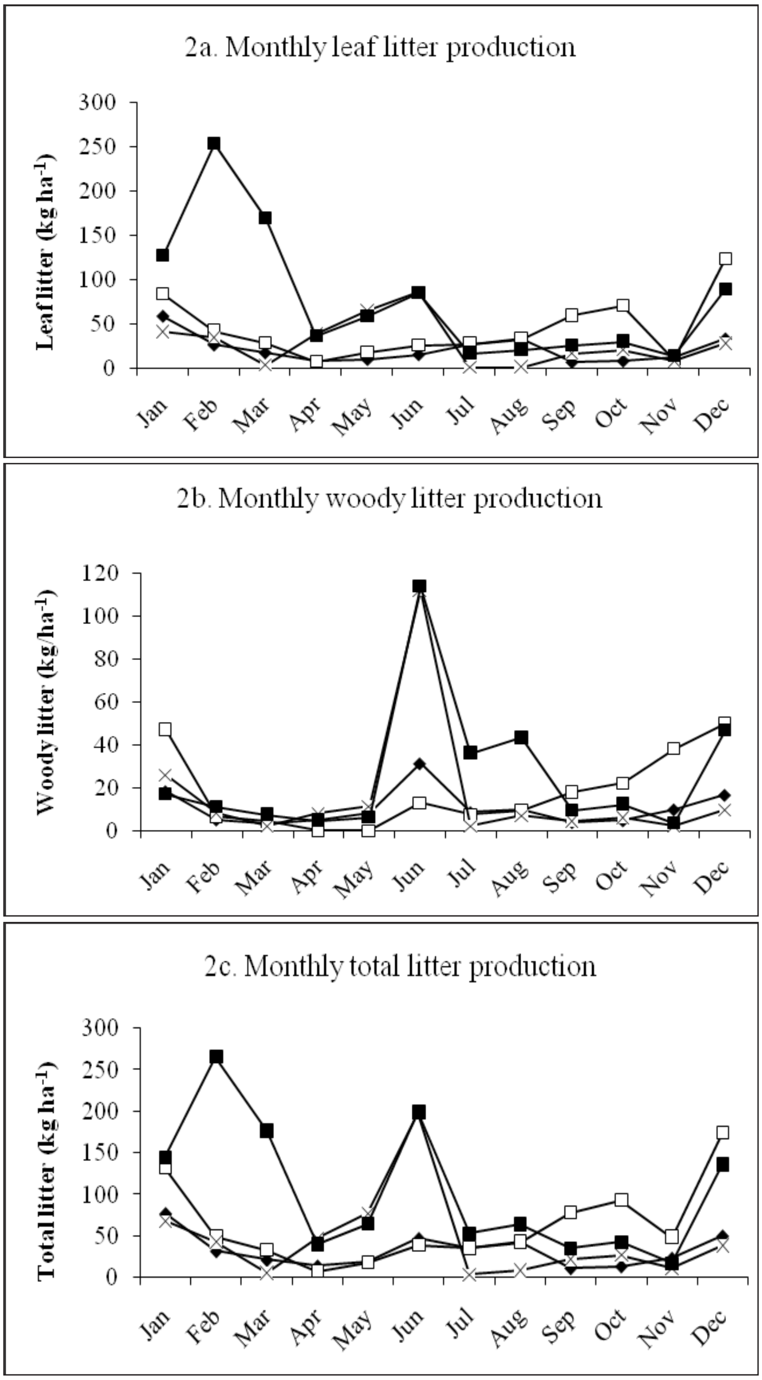
There has been variation in the seasonal patterns of litter fall within age classes. The amount and pattern of litter production is dependent of age, density and canopy characteristics (Bray and Gorham, 1964) as well as prevailing environmental factors like temperature, water and mineral nutrient availability (Jorgensen *et al.*, 1980). The variation in the seasonal patterns of litterfall is considered to be partly attributed to the growth behavior of the trees through adaptations to soil water stress during the dry season under tropical climatic conditions in the area (Yadav *et al.*, 2008). The tendency of litterfall to be more concentrated in the cool dry period may relate to decreased temperatures during this period as suggested by Yadav *et al.* (2008).

Litter decomposition

Moderate rate of decomposition was observed in the present study where, the value of decomposition constant (k) was 0.7339. Many workers have estimated decomposition constant, which shows high values in tropical forests in comparison to cool temperate and boreal forest. Swift *et al*. (1979) has reported the value of k 0.21, 0.77 and 6.0 for boreal, temperate deciduous and tropical forests respectively. According to Waring and Schlesinger (1985), the values of k for *Eucalyptus* spp. in Mediterranean woodland ranges from 0.30 to 0.94. Singh *et al*. (1993) reported decomposition constant value in *Eucalyptus* hybrid as 0.69 in 1464 rainfall region, whereas, Pande (1986) observed k value of 1.16 for eucalypt leaf litter at Dehradun, India. The moderate value of k in the present study as compared to the values reported by other workers may be attributed to quality of litter (Tateno *et al*., 2007), temperature and moisture on which the microbial activity

Table 4. Litter production in some tropical forest/plantation

Species/vegetation	Location	Litter (Mg ha^{-1})	Reference
Dry tropical forest	India	4.88–6.71	Singh, 1992
Dryland vegetation	Sonoran Desert	3.43	Búrquez *et al*., 1999
Desert scrub community	Mexico	1.20	Maya and Arriaga, 1996
E. camaldulensis plantation	IGNP, Indian desert	6.09	Bala *et al*., 2010
Acacia nilotica plantation	CSSRI, Karnal, India	3.44	Kaur, 1998
P. cineraria in agroforestry system (26 trees ha^{-1})	Semi arid Rajasthan, India	1.33	Yadav *et al*. 2008



Age: ▲ = 4-year-old (Y4); □ = 8-year-old (Y8); x = 11-year-old (Y11); ■ = 17-year-old (Y17)

Fig. 2. Monthly litter production in P. cineraria along canal command area in Indian desert.

depends. In arid areas, there may also be a less abundant detritivore component, more as a function of climate. Decomposition in such areas may be hindered by other factors also, e.g., lack of humidity (Nagy and Macauley, 1982), or because of the structural uniformity of the environment (Sargent, 1998). Moisture is more important than temperature in litter decomposition (Van Der Drift, 1963). This is why we observed moderate k value in spite of high temperature prevailing in the study area. Extreme aridity with average annual rainfall of 164 mm resulted in dry soil condition throughout the year except for a short rainy season. With mean maximum summer temperature of 41.6°C and 164 mm of average annual rainfall, the T/P ratio in the study area is extremely high (0.25), which may justify low decomposition constant value in the present study.

Nitrogen content of the substrate or the C:N ration also plays a critical role in litter decomposition (Fog, 1988) by affecting the growth of microorganisms (Alexander, 1977). The species having higher N content exhibited higher mass loss compared to the species having lower N content (Bhardwaj *et al.*, 1992). *E. camaldulensis* with a high C:N ration in between 24 and 33 (Snowdon *et al.*, 2005) is reported to have a low decomposition constant of 0.1508 (Bala *et al.*, 2010) in comparison to the decomposition constant of *P. cineratria* (having C:N ratio of 18.2 as reported by Yadav *et al.* 2008) in the present study having similar experimental set up.

No significant variation was observed among different plantation age with respect to weight loss of litter. Rate of weight loss was high during the period July to September when moisture availability was high which might have increased microbial activity favourable for decomposition. Singh and Joshi (1982) also observed high decomposition rate from June to August in arid environment and in November in a semi arid farm land (Uma *et al.*, 2014) during rainy season attributable to the availability of optimum moisture and temperature for microbial activity.

Acknowledgements

We are thankful to the Director, Arid Forest Research Institute, Jodhpur for providing necessary facilities to carry out the study. We also thank the State Forest Department, Rajasthan for extending help during the study period.

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