Litterfall, Decomposition and Nutrient Release in Sacred Forests of Western Odisha, India.

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Research

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Litterfall, decomposition and nutrient release in sacred forests of western Odisha, India.

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Background

Recognizing that litterfall and decomposition are key ecosystem functions for ecosystem stability in a terrestrial ecosystem, litterfall and decomposition in four sacred forests were studied from western part of Odisha. The present study focuses on the detailed aspects of litter dynamics, decomposition and consequent release of nutrients to the forest floor. The results obtained in this study will be beneficial in understanding the ecosystem functioning associated with nutrient cycling, which helps in determining possible management strategies for optimization of ecosystem functioning and productivity of these sacred forests.

Results

Litterfall and standing litter showed a seasonal pattern with most of the litter accumulated during the dry seasons and lowest in the rainy season. However, no significant difference was observed between the litterfall patterns of the sacred forests. The annual turnover rate (K_L) was found to be in the range of 3.59/yr to 4.22/yr in studied sacred forests. The litter decomposition study was performed by litter bag technique and almost 95% of mass loss was observed within a period of 6 months. Such fast decomposition leads to faster rate of nutrient release across the sites. The studied elements can be set in the following order as regards to their return to the topsoil during decomposition in the order of K (Potassium) > N (Nitrogen) > P (Phosphorus). The approximate amount of nutrient released to the forest soil is quantified in the range of 184.76 to 33.61kg/ha of NPK (Nitrogen, Phosphorus and Potassium) in different sacred forests.

Conclusion

Such nutrient release and dynamics in sacred forests, may contribute an effective nutrient flow to the topsoil as well as to the surrounding agricultural landscapes boosting agricultural productivity and sustainability. This signifies the role of sacred forests in rendering an important ecological service in terms of nutrient cycling.

Keywords:

Litterfall, litter decomposition, Sacred forests, Ecosystem services, Nutrient cycling

Background

Plant shed parts of their biomass (litterfall) periodically, which is a key ecological process in terrestrial ecosystems that serves as a linkage between the vegetation and the soil (Vitousek 1984; Lowman 1988; Sayer 2006; Huang et al. 2017; Chakravarty et al. 2019; Zhu et al. 2019). Litter inputs and their decomposition improves the soil structure and function through the soil organic matters and the nutrient pool (Bargali et al. 1993; Yu et al. 2004; Rawat et al. 2010; N'Dri et al. 2018). Litterfall and decomposition also contributes to long term carbon storage, ecological restoration and regeneration dynamics (Watanabe et al. 2013; Campos et al. 2017; Tian et al. 2017). The presence of litter in the forest floor can potentially increase seedling diversity (Molofsky and Augspurger 1992) and can change plant recruitment rates by creating an insulating layer and reducing soil evaporation and the density of weeds (Facelli and Pickett 1991).

Tropical forests are characterized by a strong seasonality in their leaf litterfall pattern (Zhang et al. 2014; Becker et al. 2015; Wagner et al. 2016; Nakagawa et al. 2019), and the seasonality depends on the vegetation characteristics, species composition and plant phenological responses to environmental variation (Cuevas and Lugo 1998; Zalamea and Gonzalez 2008; Schilling et al. 2016; Souza et al. 2019). In tropical dry forests leaf loss mostly occurs during the dry season (Barlow et al. 2007; Zhang et al. 2014). A massive accumulation of litter mass on the forest floor is a common observation in the tropical dry deciduous forest (Murphy and Lugo 1986; Lopes et al. 2015).

In a forest ecosystem the productivity of the tree species depends on the litter decomposition and rapid turnover of litter nutrients (Vendrami et al. 2012; Rai et al. 2016).

Through litter decomposition the complex organic matters in leaf litter disintegrates into simpler form by the action of soil microbial community and enriching the soil with the supply of vital nutrients (Gessner et al. 2010; Rottmann et al. 2010). Nutrient release from the decomposed litter is recognized as an available nutrient (Li and Ye 2014) for the growth of plant and improvement of soil quality (Maclean and Wein 1978; Moore et al. 2006). Litter decomposition rates vary with the species composition, litter quality, climatic factors and the soil microbial population in different forest types (Krishna and Mohan 2017; Chakravarty et al. 2019). Temperature and precipitation are the prime abiotic factors, whereas litter chemistry and decomposers population in soil are the principal biotic factors in determining litter decomposition rates (Trofymow et al. 2002; Fierer et al. 2005; Davidson and Janssens 2006; Cornwell et al. 2008; Prescott 2010; Berg and McClaugherty 2014).

Sacred natural sites including sacred forests and sacred groves have coexisted with human population for centuries. The sacred forests of Odisha represent relatively undisturbed vegetation due to protection by indigenous communities for religious and spiritual values. These sacred forests with rich biodiversity have a stable ecosystem and are considered as biocultural conservation centers (Pradhan and Ormsby 2020). But the ecosystem functioning of the sacred forests in the state of Odisha representing the tropical dry deciduous forest has not been thoroughly studied in terms of litter production and decomposition.

As the litter decomposition is a highly complex process that involves a number of physical, chemical and biological factors, there is little information about the litter decomposition rate and the various factors in forest ecosystems of tropical dry deciduous forests of Odisha. The information related to litterfall and litter decomposition from the sacred forests are also limited to only few studies (Khiwtam and Ramakrishnan 1993; Rajendra Prasad et al.

2000; Pragasan and Parthasarathy 2005). Such studies pertaining to litterfall pattern and the decomposition leading to the carbon enrichment and nutrient cycling are quite essential to boost the ecological processes of the sacred forests. The present study focuses on the detailed aspects of litter dynamics, decomposition and consequent release of nutrients in four sacred forests located in the western part of Odisha, India. The results obtained in this study will be beneficial in understanding the ecosystem functioning associated with nutrient cycling, which helps in determining possible management strategies for optimization of ecosystem functioning and productivity of these sacred forests.

Results

Dynamics of litterfall production

In all the sites, the monthly litter production data during the study period (Figure 3) showed a peak during the month of March. The monthly litter production pattern among the sites did not vary significantly (p-value = 0.3191). The quantum of annual litterfall was the highest in the Medha (11.32 Mg/ha), followed by Dedungri (10.28 Mg/ha), Papanga (8.94 Mg/ha) and least in Andhari (8.59 Mg/ha). In all the sites, the largest proportion of the litter was observed to be the leaf litter with a range of 81-83%. The proportion of litterfall fractions were in order of leaves > twigs > branches > others for all sites.

< Insert Figure 3 here>

Standing litter and litter turnover rate (K_L)

For each sacred forest the amount of standing litter on the floor showed a pattern identical to that of litterfall. The total standing litter showed the maximum value during March and the minimum value during August and September. The month wise data of standing litter across the four sacred forests did not vary significantly (p-value = 0.1884). The mean annual standing litter was observed to be maximum for Medha (2.68 Mg/ha) followed by Dedungri (2.51 Mg/ha), Papanga (2.47 Mg/ha) and least for Andhari (2.39 Mg/ha). The annual turnover rate (K_L) was found to be in the range of 3.59/yr in Andhari to 4.22/yr in Medha. The calculated residence time (T) of litter in different sites varied from 87 to 102 days (Table 3) and was ranked in the order Medha < Dedungri < Papanga < Andhari.

<Insert Table 3 here>

Litter decomposition and Nutrient return

The *insitu* litter decomposition experiment in the four sacred forests demonstrated a phasic litter decomposition trend (Figure 4). With the progress of time total mass loss was increased but no uniformity was observed in the monthly loss of litter weight. The rate of decomposition was found to be relatively higher in first month then deceased for the second month and then again from third months the rate was found to increase in all forest stands. Litter mass loss across the four sites did not exhibit any significant difference (p-value = 0.9079). In all the four sites, about 95% of the total mass was found to be lost within the six month of the decomposition study. The litter decay rate coefficient (k) varied from 5.75/yr (Andhari and Papanga) to 6.65/yr (Medha). The time taken for 50% and 99% decay also varied from 38 to 44 days and 274 to 318 days respectively.

<Insert Figure 4 here>

The initial chemical characteristics of mixed leaf litter varied significantly among the four sacred forests (except Carbon content) (Table 4). The leaf litter content of Papanga had the highest N, P and K concentration than other forests. On the basis of the relatively higher concentration of N, P, K and lower ratio of C:N, the mixed litter of Papanga was considered to be of relatively better quality than others. The litter quality in different sites were in order of Papanga > Dedungri > Andhari > Medha. The monthly variation in nutrients return (N, P, K) from the litter decomposition followed a pattern that was consistent with the litter mass loss in each forest stand. The rate of nutrient release did not vary significantly ($P = 0.996474$) among the sites but varied significantly with respect to the months ($P = 0.000136$). Papanga had the highest percentage of nutrient loss (96.57%) after the six months of decomposition followed by Andhari (95.36%), Dedungri (94.18%) and least in Medha (92.38%).

During the decomposition of the leaf litter, concentration of N and P gradually increased in the residual litter of all the forest stands. The concentration of C remains more or less stable in Andhari and Medha but decreased in Dedungri and Papanga. However, the K concentration significantly declined in all the forest stands (Figure 5). The nutrient loss pattern for individual nutrient content suggested no significant difference in the nutrient loss of C ($P = 0.9836$), N ($P = 0.9778$), P($P = 0.7221$) and K ($P = 0.9615$). The nutrient release pattern showed highest release of K in all the four sites in following order: Andhari (99.2%) > Papanga (99.09%) > Medha (98.84%) > Dedungri (98.72%). Similarly the N loss is in the order of Papanga (95.08 %) > Andhari (95.06%) > Dedungri (93.58%) > Medha (92.26%). P had the lowest release pattern among the nutrient in all the sites in the order of Papanga (95.34%) > Andhari (90.72%) > Dedungri (88.93%) > Medha (80.54%).

< Insert Figure 5 here>

On the basis of the litter fall data along with their nutrient contents in different sacred forest sites, the annual return of different nutrients to the forest floor were calculated. The approximate amount of nutrient released to the forest soil is quantified to be 184.76 kg/ha of NPK (Nitrogen, Phosphorus and Potassium) in Papanga, followed by 133.61kg/ha of NPK in Dedungri, 110.85kg/ha of NPK in Medha and least 99.11 kg/ha of NPK in Andhari.

Discussion

The annual litterfall data of different sacred forest sites as estimated in the present study, are within the range of litterfall data of different tropical forests of the world (Zhang et al. 2014). However, the data are noted to be comparatively higher than that of few tropical dry deciduous forests of India (Rai et al. 2016; Shukla et al. 2017). The pattern of monthly litterfall with peak during dry season as observed in the study is in confirmation with patterns noted by Barlow et al. (2007) and Zhang et al. (2014). The observation that the leaves as the largest proportion of the litter (80-83%) in the study is in agreement with the findings of Rajendra Prasad et al. (2000), Pragasan and Parhasarathy (2005), Zhang et al. (2014) and Nakagawa et al. (2019), who reported leaf litter as the major fraction of total litter in tropical forests.

Standing litter mass usually reflects the turnover of the organic matter in any terrestrial ecosystem (Spain 1984). Lower range of standing litter mass as noted in the present study is therefore an indication of faster litter turnover rate in different sacred forest sites. There have been several reports about the faster turnover rate of litter in tropical dry/moist deciduous forests (Sanches et al. 2008; Prasangan and Parthasarathy, 2005; Scott et al. 1992; Gholz et al. 2000; Rajendra Prasad et al. 2000).

The leaf litter decomposition did not show significant variation ($P = 0.9923$) among the sites. This may be due to occurrence of the sites in the same agro-climatic zone, having no significant variation among many of the soil physico-chemical characteristics. Achievement of

95% weight loss during first six months of the litter decomposition, is in conformation with Swift et al. (1979), who also reported about such trend in dry deciduous forest floor with lateritic soil. However, this rate was faster than the studies from tropical dry forests of Gujrat (Mehta et al. 2013); Subtropical forest of North east India (Devi and Yadava 2010) and tropical dry deciduous forest of Chattisgarh (Bargali et al. 2015) in India. Such faster decomposition usually leads to the faster release of nutrients to soil for further plant uptake (Isaac and Nair 2006) and signifies the relevance and the role of litter in plant nutrition.

The nutrient release pattern did not show any significant variation among different sites. However, there observed a difference with respect to the release of types of nutrients in different sites. The release of K was faster compared to N and P during the litter decomposition. This may be due to its high mobility as a leachable cation during decomposition (Peterson and Rolfe 1982; Berg and McClaugherty 2014). The extensive leaching of K from the leaf litter was also reported by Peterson and Rolfe (1982); Cattanio et al. (2008) and Lanuza et al. (2019). The proportionate nutrient specifically N and P in the remaining litter was found to be increase from initial litter content till end of the decomposition period. This may be attributed to microbial or nonmicrobial immobilization of nutrients from the residual leaf litter, during the process of decomposition (Devi and Yadava 2010; Cattanio et al. 2008; Parson and Congdon 2008; Sarkar et al. 2016; Lanuza et al. 2019).

Conclusions

The study in general reveals no distinction between the sacred forest and natural forests with respect to the litter production, decomposition and nutrient dynamics. Hence, such people participatory conserved sacred forest sites mimics the attributes of natural forests. The faster litter decomposition rate with rapid nutrient release pattern in sacred forest sites is expected to supports the optimal levels of soil nutrient pools, which in turn is going to support healthy above ground vegetation and consequently to the ecosystem stability. Besides, such nutrient release and dynamics in sacred forests, may contribute an effective nutrient flow to the surrounding agricultural landscapes boosting agricultural productivity and sustainability. This signifies the role of sacred forests in rendering an important ecological services for the surrounding region. If sacred forests are disturbed, this can affect the ecosystem functioning and stability and may lead to desertification. The dynamics of litter production, decomposition and nutrient release should therefore receive more attention for effective management of the sacred forests.

Methods

Study Area

The study was conducted in four different sacred forests of western Odisha: Andhari, Dedungri, Medha and Papanga located in Jharsuguda, Sambalpur, Sundargarh and Bargarh districts respectively (Figure 1).

< Insert Figure 1 here>

The detailed information regarding the selected sacred forests, their size, area, associated ethnic gropus and geographical locations are presented in Table 1. The vegetation of these sites can be categorized as tropical dry deciduous types with *Shorea robusta* Gaertn., *Cleistanthus collinus* (Roxb.) Benth. Ex Hook. f. *Buchanania cochinchinensis* (Lour.) M. R. Almeida., *Terminalia tomentosa* Wight & Arn, *Madhuca longifolia var. latifolia* (Roxb.) A. Chev and *Lagerstroemia parviflora* Roxb as some of the dominant tree species (Pradhan et al. 2019).

< Insert Table 1 here>

The general climate of the study areas can be considered as Tropical Savanna Climate. Tropical savanna climate is characterized by mean monthly temperature above 18°C. The rainfall is seasonal i.e. during south-west monsoon from mid of June to end of September. The year is categorized in to 4 seasons viz. winter (Dec-Feb), summer (Mar-May), Monsoon (Jun-Aug) and Post Monsoon (Sep-Nov). During the summer period, the air temperature may go up to as high as 45° C with relative humidity value of around 40%. Winter season begins from November to the end of February with December as the coolest month with average temperature of about 13° C. The Average temperature and rainfall data for each of the site have been represented in Figure 2.

< Insert Figure 2 here>

Litter sampling and analysis

Litterfall was estimated at monthly interval for a period of one year starting from January 2017 to Dec 2017. Fifteen traps of 1 m × 1 m × 0.15 m (length × breadth × height) were placed randomly within each sacred forest. The litter was collected throughout the year and were segregated into four fractions, viz., leaf, twig, branch, other parts. The biomass of each components was determined after oven-drying the samples at 80°C for 48 hours or until constant weight was achieved.

Litter decomposition

Nylon bag (Mesh size of 1 ×1 mm) technique was used to study the decomposition of leaf litter of four forest sites (Crossley and Hogland 1962). Fresh leaf litters from all the sites under investigation were randomly collected during the peak litterfall period (February - March) and air dried. Air dried litter samples of 20g each were placed in 20 cm x 20 cm litter bags and ninety such bags were prepared for each study sites. Litter bags were placed on the soil surface just below the litter layer and were placed following complete randomized experimental design. At monthly interval 6 bags were recovered from each site. The residual litter from the bag was washed carefully to remove all the soil particles and then oven dried at 80^0C for 48 hours, weighed and powdered for chemical analysis.

Litterfall Analysis

Annual litterfall data for each site was calculated by summing the monthly data of each plot. Monthly litterfall data was obtained from average value of all litter traps placed in a site. Litter turnover rate (k_L) was calculated using mathematical model of Reiners and Reiners (1970)

$$K_L = \frac{L}{X_L}$$

Where, L = annual litterfall (kg/ha/yr) and X_L= Mean annual standing crop (kg/ha)

Turnover time (T) was calculated as a reciprocal of turnover rate:

$$T = \frac{1}{K_L}$$

where, T is time (in year)

Organic matter decay constants for the leaf litters were computed using the Olson (1963) negative exponential decay model:

$$\frac{X}{X_0} = \exp(-kt)$$

Where X is the weight remaining at time t, X_0 is the initial weight, *exp* is the base of natural logarithm, k is the decay rate coefficient, and t is the time. Further, the time required for 50% (t_{50}) and 99% (t_{99}) decay were calculated as per Bockheim et al. (1991).

$$t_{50} = \frac{0.693}{k}$$

$$t_{99} = \frac{5}{k}$$

The total nutrient return for each site was estimated as the sum of the monthly nutrient return during the study period. Nutrient content of decomposing leaf litter was derived as:

$$\%\ Nutrient\ remaining = \left(\frac{C}{C_0}\right) \times \left(\frac{DM}{DM_0}\right) \times 100$$

Where C is the concentration of nutrient in litter at the time of sampling, C_0 is the concentration of nutrient in the initial litter samples, DM is the mass of litter at the time of sampling, and DM_0 is the mass of initial litter samples kept for decomposition (Bockheim et al. 1991).

Chemical analysis

All the tree species were considered together as mixed species. All the leaf litter samples collected from the floor as well as from litter bags were washed and dried in oven at 80°C for 48 hrs, finely ground and stored for nutrient analysis. Total C, N, P and K contents of the tissues and litter material processed above were determined by standard methods. The ash content was determined by igniting 1 g of powdered litter sample at 550 °C for 6 hour in a muffle furnace. A total of 50% of the ash free mass was calculated as the carbon(C) content (Allen 1989). For total N determination the finely ground samples were digested in a block digester with conc. H2SO4 using Kjeltabs as catalyst and total N will be determined by distillation and titration methods (Allen et al. 1974). Total phosphorus concentration was determined by molybdenum-blue method (Allen et al. 1974) after digestion of samples with tri-acid mixture (H2SO4-HClO4-HNO3). Potassium concentration was determined by flame photometry (Jackson 1958) after digesting the plant samples with tri-acid (H2SO4-HClO4-HNO3) mixture.

Statistical analysis

All the data were checked for normal distribution and homogeneity of variance using Shapiro-Wilk test and Leven's test with stats statistical package in R software platform. Kruskal – Wallis rank sum test was applied to the data if these assumptions were not satisfied. For normalized data two way analysis of variance (ANOVA) performed among the four different sacred forests. Pearson's coefficient was used to test for linear correlation between the monthly litterfall and climatic factors and between mass loss and leaf litter biochemical properties. The packages that used for correlation analysis included corrgram and corrplot. All statistical procedures were performed with $\alpha = 0.05$ threshold for significance.

< Insert Table 2 here>

Declarations:

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Conflicts of interest/Competing interests

The authors declare no conflicts of interest

Availability of data and material

The data supported to the conclusions of this article are included within the article. Any quaries regarding these data may be directed to the corresponding author.

Code availability

Not Applicable

Authors' contributions

The first author AP conducted the field work and set up the experiment, collected and analyzed the data. The second author NB designed the work and edited the manuscript.

Ethics approval

Not Applicable

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Table 1. Sacred forest sites with their geographical location, associated deities and tribes.

Sacred forests	Approx. Size	District	Deity	Assoc. Tribes
Andhari	1000 ha	Jharsuguda	Andhari	Gond
Dedungri	50ha	Sambalpur	Manchaka Rishi	Gond
Medha	25 ha	Sundargarh	Shiva	Bhuya, Jhara
Papanga	250 ha	Bargarh	Budharaja	Bhil

Table 2. Soil physico chemical attributes of (0-30cm) in four tropical dry deciduous sacred forests

Soil parameters	Andhari	Dedungri	Medha	Papanga	p-value	Significance
pH	5.81	5.87	5.94	5.59	0.07622	NS
Electron conductivity	0.2	0.19	0.13	0.21	0.2498	NS
Moisture (%)	6.08	5.81	6.40	6.67	0.9679	NS
Carbon (%)	2.41	2.00	2.08	0.95	0.009408	***
Nitrogen (%)	0.17	0.16	0.15	0.06	0.002591	***
Phosphorus (Kg/ha)	7.61	14.12	14.52	38.48	3.36e-06	***
Potassium (Kg/ha)	197.75	195.61	192.66	199.85	0.9349	NS
C:N	14.87	13.50	14.47	14.77	0.6328	NS

Table 3. Annual litterfall and turnover rates in different sacred forests.

Parameters	Andhari	Dedungri	Medha	Papanga
Annual litterfall (Mg/ha/yr)	8.59	10.28	11.32	8.94
Mean annual standing crop (X_L) (Mg/ha)	2.39	2.51	2.68	2.47
Litter turnover rate (K_L)	3.59	4.10	4.22	3.62
Turnover time in year (T)	0.278	0.244	0.237	0.276
Residence time in days	102	89	86	101
Decay rate coefficient (k)	6.65	6.12	5.75	6.65
Time required for 50% decomposition in years (t_{50})	0.10	0.11	0.12	0.10
Time required for 99% decomposition in years (t_{99})	0.75	0.82	0.87	0.75

Table 4. Initial biochemical constituents of litter collected from different sacred forests.

Leaf properties	Andhari	Dedungri	Medha	Papanga	p-value	Significance
%C	47±0.63	46.67±0.52	46.67±0.52	46±1.55	0.5159	NS
%N	0.59±0.03	0.63±0.07	0.54±0.05	0.68±0.06	0.006546	***
%P	0.26±0.08	0.31±0.02	0.18±0.02	0.71±0.03	0.0001977	***
%K	0.36±0.05	0.44±0.05	0.34±0.07	0.75±0.03	0.0006696	***
C/N	79.58±3.69	74.78±7.97	87.17±9.48	68.22±5.60	0.006239	***
C/P	192.19±49.39	152.96±8.83	268.72±26.73	64.65±3.86	0.0001977	***
N/P	2.41±0.59	2.07±0.29	3.13±0.59	0.95±0.11	0.0004914	***

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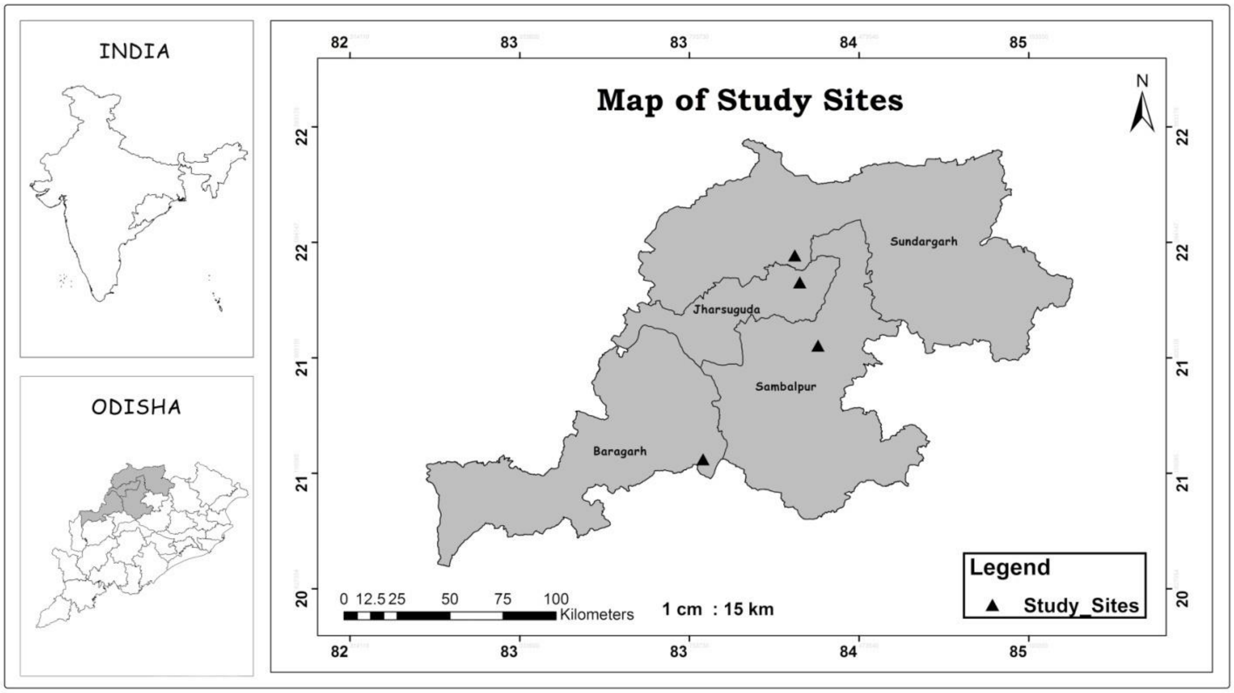

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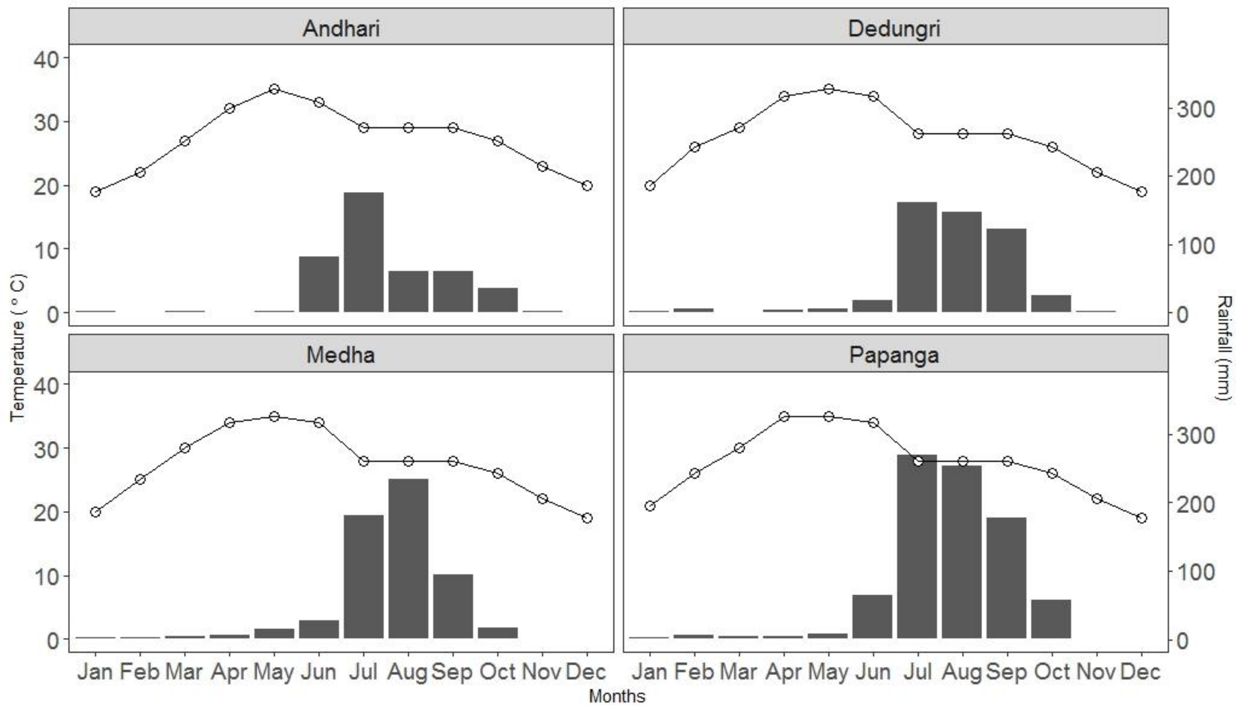

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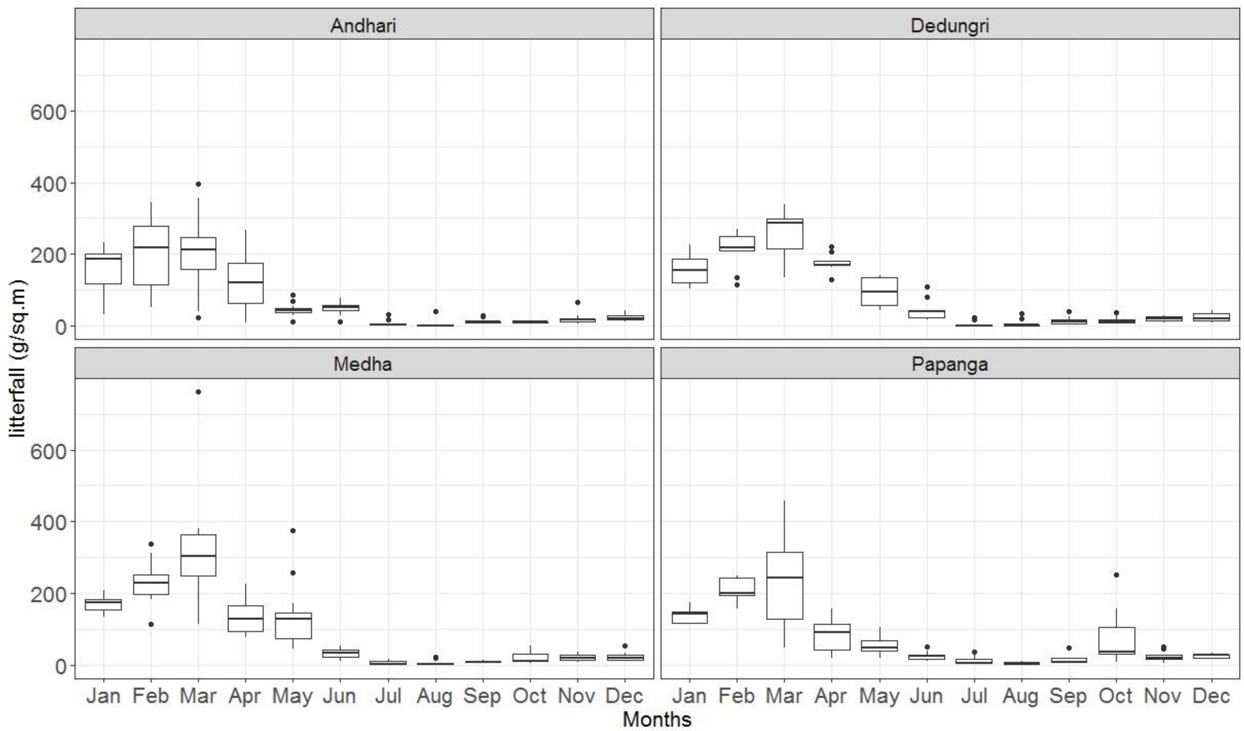

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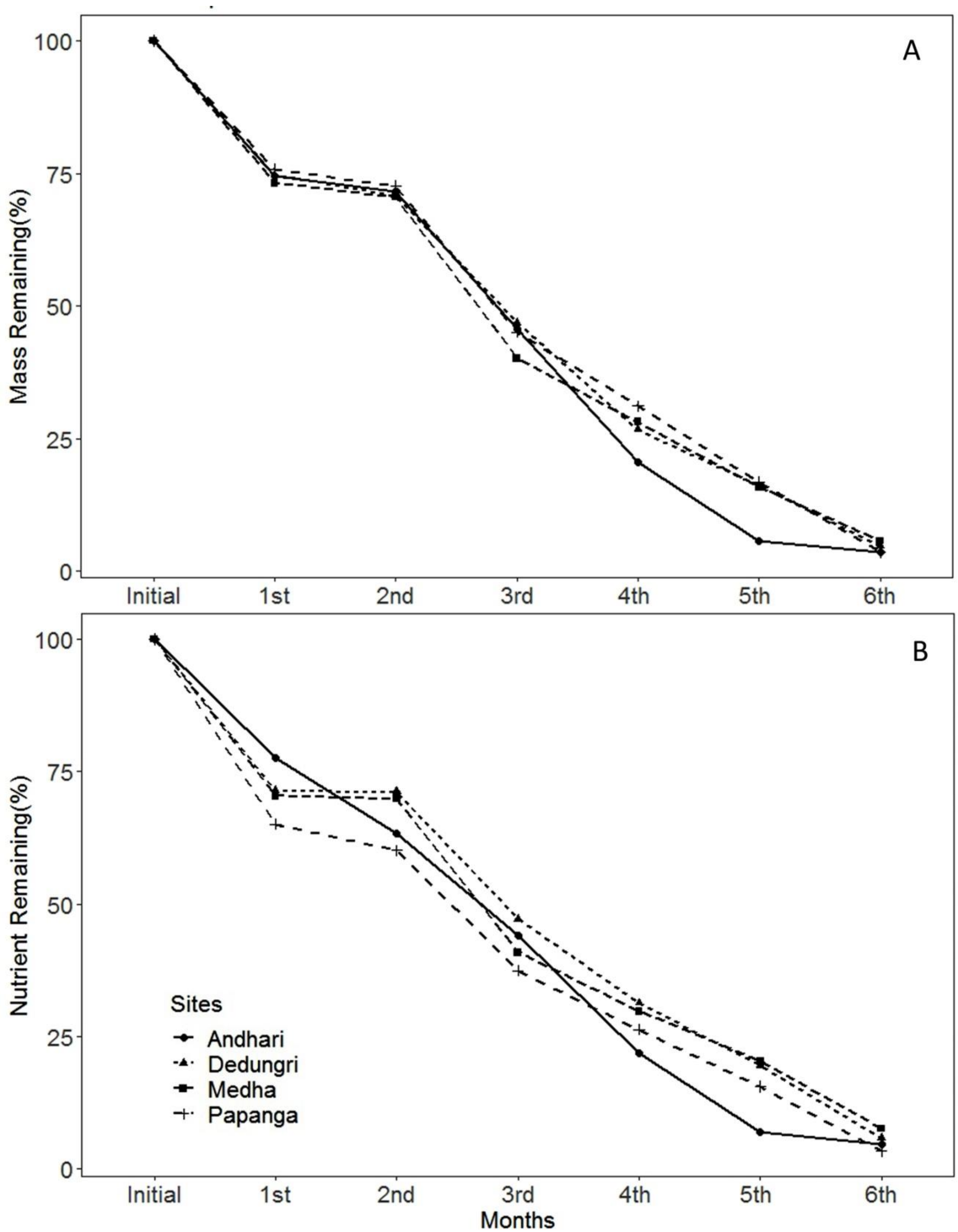

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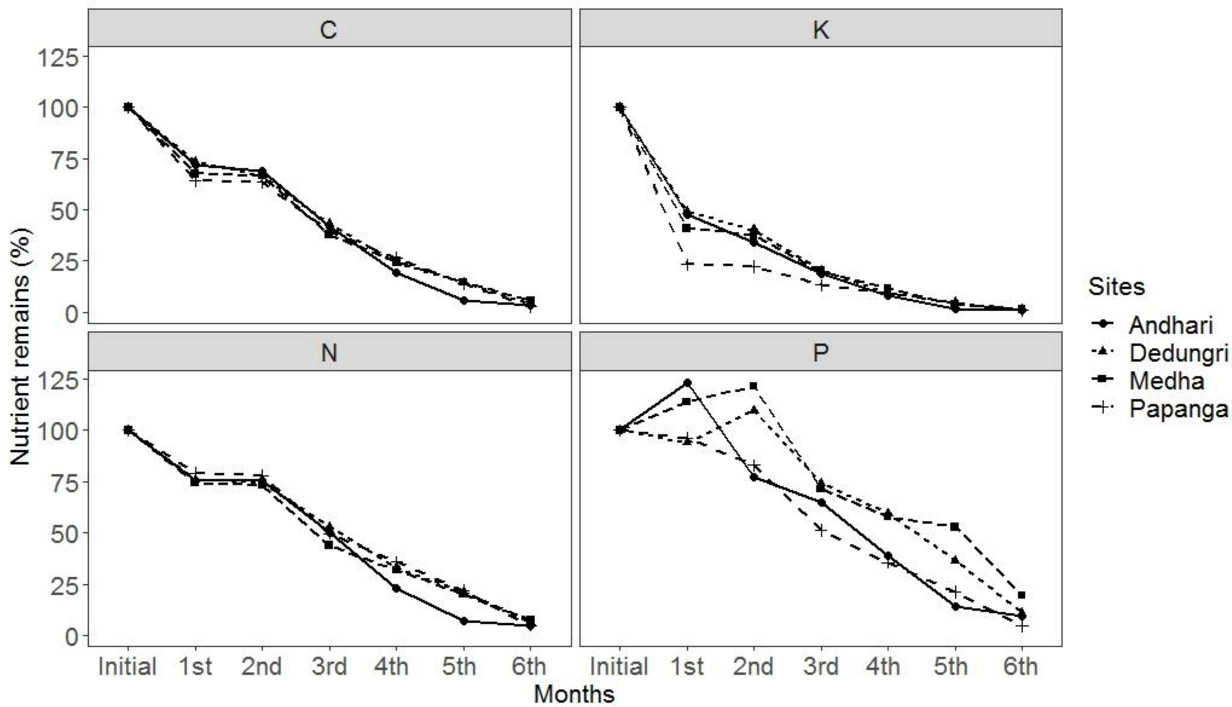

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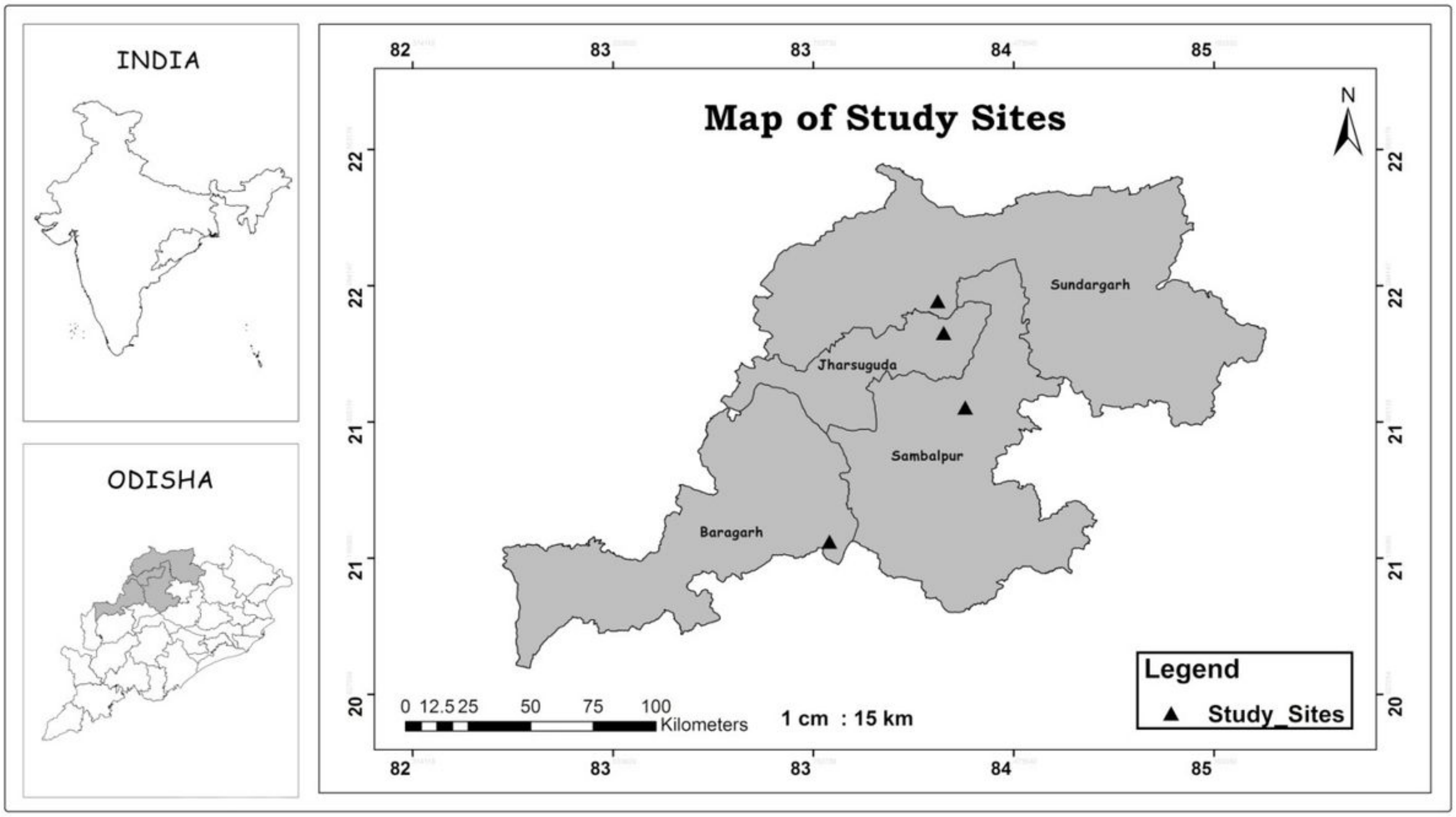


Figure 1

Location of Study sites in four different districts (Sundergarh, Jharsuguda, Sambalpur and Bargarh) of Odisha.

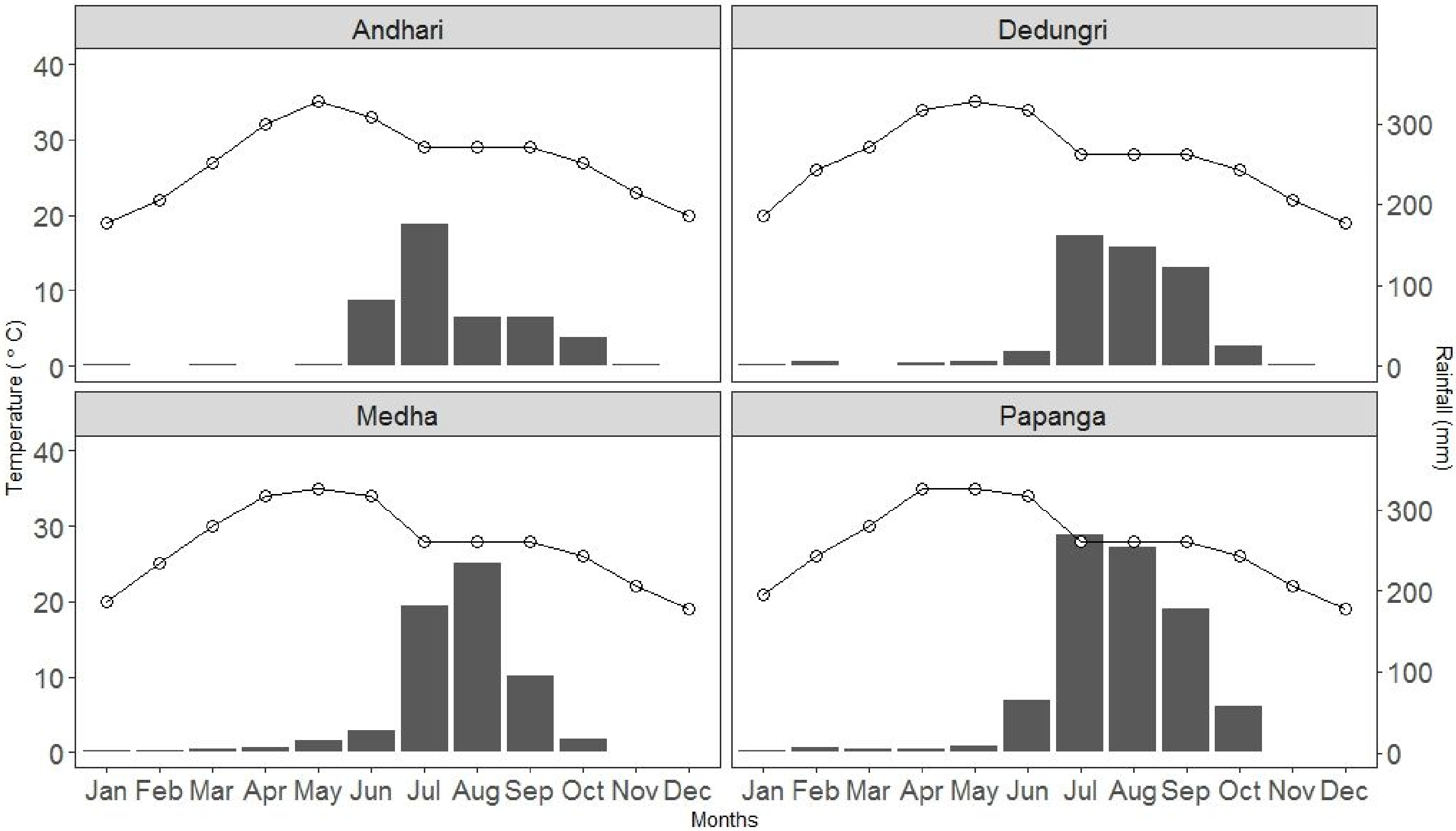
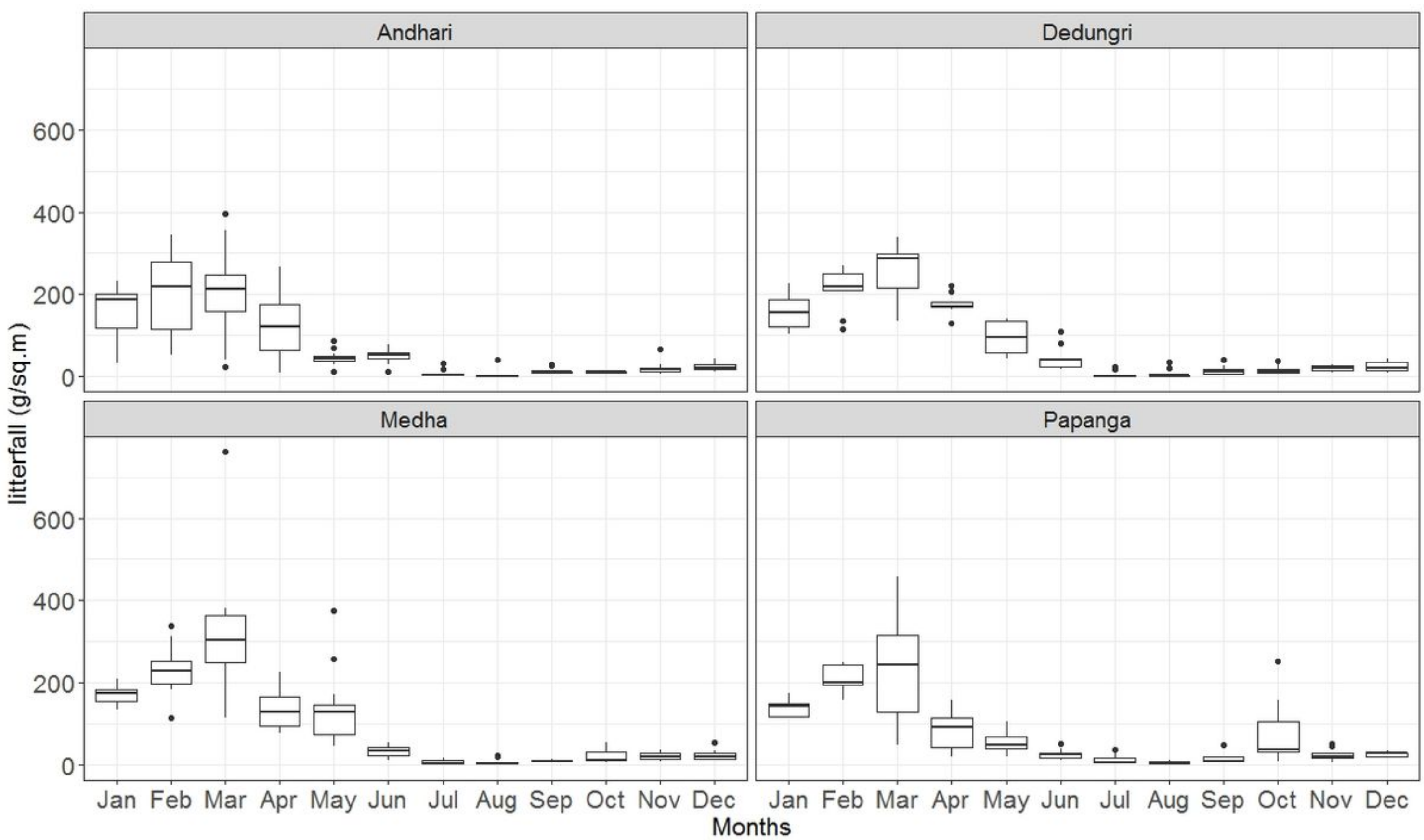


Figure 2

Average monthly temperature and rainfall of the study sites for 2017.



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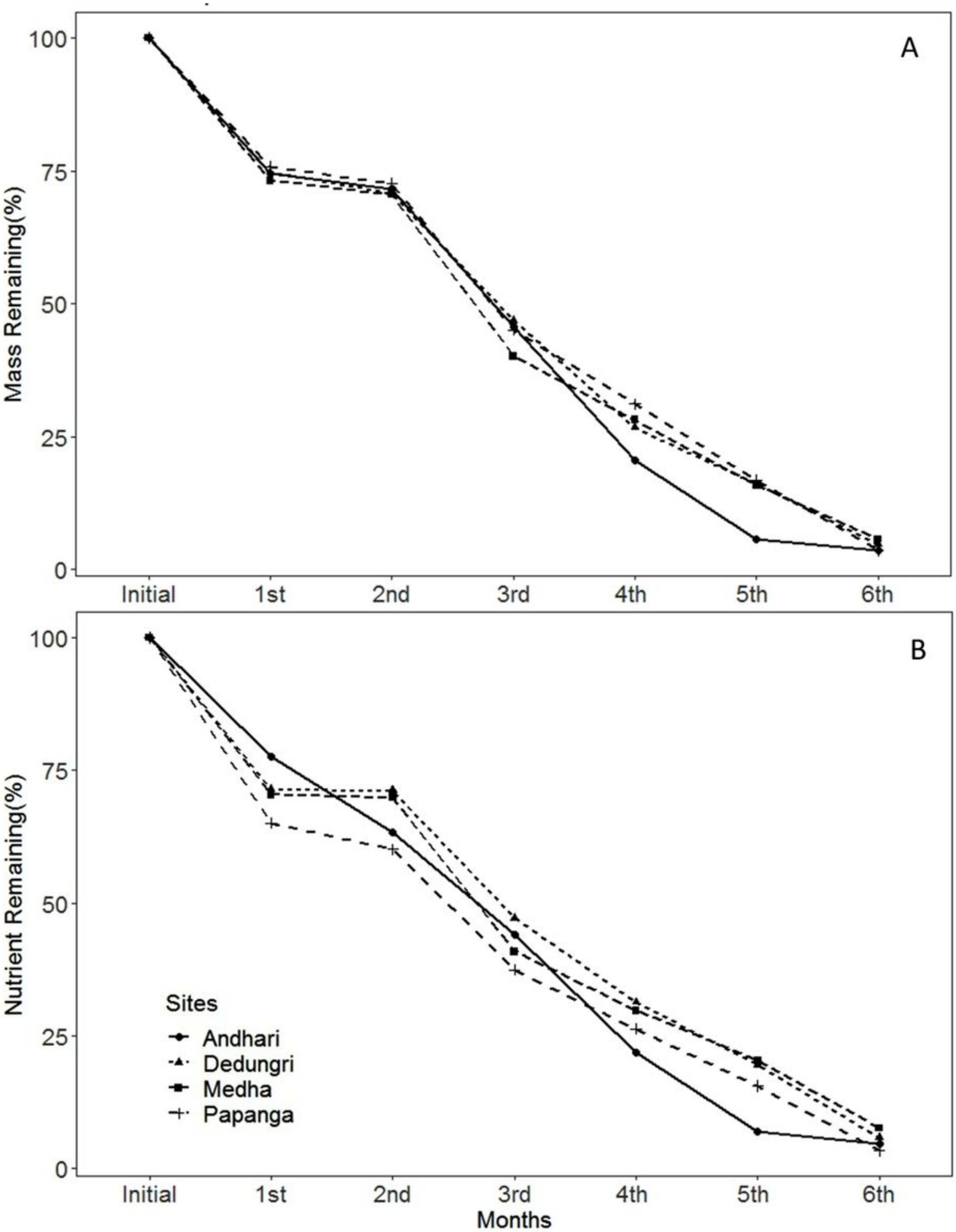
Monthly variation of litterfall (g/m2) in different sacred forests.



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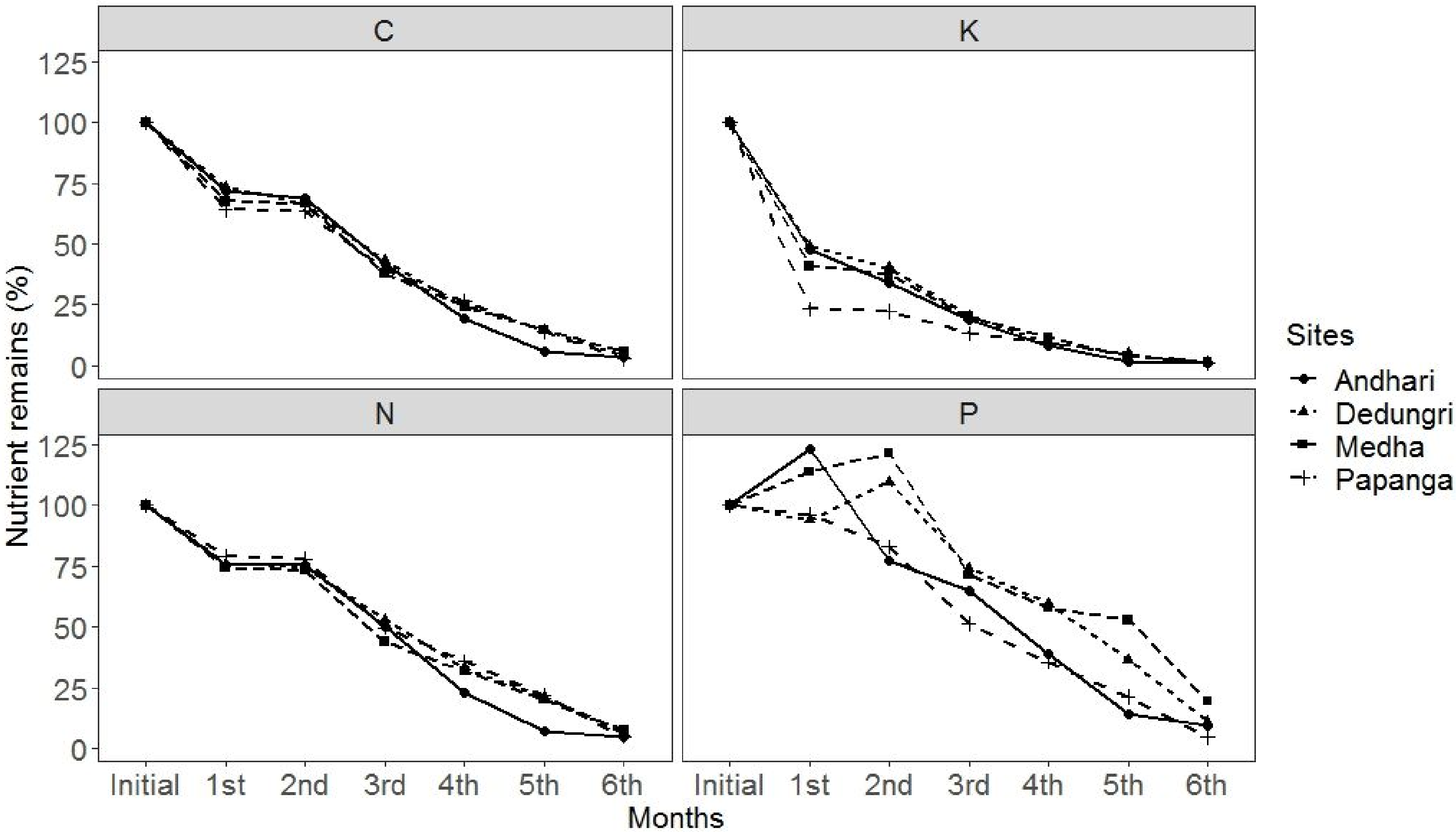

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Nutrient loss or remains during the decomposition period.