RESEARCH ARTICLE

Net Primary Productivity and Budget of Nitrogen and Phosphorus in the Herbaceous Layer of a Tropical Dry Deciduous Forest in Rajasthan in Northwest India

Atar Singh Yadav*, Rajesh Kumar Yadav
DOI: 10.18811/ijpen.v6i02.06

Abstract

The net primary productivity and budget of total nitrogen and available phosphorus in the herbaceous layer was studied in a tropical dry deciduous thorn forest in Rajasthan state of north-western India. The average net primary productivity of the herbaceous layer was 242 g $m^{-2}yr^{-1}$, it was the highest (257 g m^{-2} yr^{-1}) at the top and the lowest (218 g m^{-2} yr^{-1}) at the middle of the hill slope. Out of the herbaceous species present in the study site, 29 species contributed more than 1 g m^{-2} biomass with the highest contribution by *Brachiaria ramosa* (54%) and *Achyranthes aspera* (44%). The herbs allocated about 10 and 90% of total biomass to roots and above-ground parts, respectively. The highest content of nitrogen in the soil, biomass, and litter was 181, 3.4, and 1.7 g m^{-2}, respectively, during the rainy season in July. A similar pattern was observed for phosphorus. The annual uptake of nitrogen and phosphorus by vegetation was 3.84 g m^{-2} and 0.76 g m^{-2}; 19 and 16%, respectively, return to the soil through litterfall. Before the litterfall occurred, the nitrogen, a vital element was translocated into below-ground parts. This is a strong strategy for the conservation of nitrogen. Phosphorus, however, did not show such a trend. This interesting observation of the study strongly indicated that a sufficient amount of nutrients are retained in the litter during the dry summer period.

Keywords: Biomass, Herbaceous vegetation, NPP, Soil, Tropical deciduous forest.

International Journal of Plant and Environment (2020); **ISSN:** 2454-1117 (Print), 2455-202X (Online)

Introduction

Elliott *et al.* (2015) on the basis of their study in eastern deciduous forest ecosystems suggested that the role of herbaceous vegetation in influencing ecosystem processes in deciduous forests is generally unknown, however, the herbaceous layer affects above-ground net primary productivity and regeneration of tree species. The herbaceous vegetation is a dynamic layer that indicates the environmental changes in an ecosystem (Singh *et al.*, 2017). The primary productivity of herbaceous layer has been studied in *Apluda* community in Aravalli hills at Udaipur (Vyas & Vyas, 1978), in a tropical dry deciduous forest in Varanasi (Singh & Singh, 1980), in savannah type ecosystems in Sambalpur, Orissa (Pardhan & Dash, 1984; Joshi *et al.*, 1990) and under tree plantations (Das *et al.*, 2008). However, studies on the role of the herbaceous layer in the cycling of essential elements in tropical dry deciduous forests are limited. Pandey and Singh (1990) studied the storage and cycling of nitrogen in the early successional grassland community at Varanasi, and Sharma and Upadhayaya (2002) evaluated the primary productivity and nutrient return in herbaceous vegetation in an arboretum in Jaipur. It has also been suggested that nutrients not only maintain the normal physiological activities of the living organisms but also influence the soil system (Singh & Mudgal, 2000). It is hypothesized that in semi-arid regions the herbaceous vegetation plays important role in primary productivity and nutrient cycling in the tropical dry deciduous forest ecosystem. The evaluation of the primary productivity and nutrient status of the herbaceous layer may throw some light on the natural processes of nutrient conservation in these forests. Hence, the present study was carried out in a tropical dry deciduous forest in the Rajasthan state of Northwestern India.

Department of Botany, R. R. Autonomous College, Alwar-301001, Rajasthan, India

***Corresponding author:** Dr. Atar Singh Yadav, Department of Botany, R. R. Autonomous College, Alwar-301001, Rajasthan, India; Mobile: +91-9414681566; Email: atarsingh_1010@rediffmail.com

How to cite this article: Yadav, A. S., & Yadav, R. K. (2020). Net primary productivity and budget of nitrogen and phosphorus in the herbaceous layer of a tropical dry deciduous forest in Rajasthan in Northwest India. International Journal of Plant and Environment 6(2): 129-136.

Source of support: Nil

Conflict of interest: None

Submitted: 22/02/2020 **Accepted:** 25/04/2020 **Published:** 30/04/2020

Materials and Methods

Study Area

The Aravalli mountain range supports tropical dry deciduous forest in the semi-arid regions of Rajasthan. The hilly topography creates spatial heterogeneity which sustains moderate species diversity of low growing trees. Since the canopy of these forests is relatively open, there is a growth of rich herbaceous stratum; in the rainy season (July–September) which receives about 90 percent of 640 mm annual rainfall. The cold and hot dry conditions prevail for the rest of nine months in a year. The Bala-fort Reserve Forest is situated in the Aravalli mountain ranges in the state of Rajasthan (27°4′ to 28°4′ N and 76°7′ to

77°13′ E) in the Northwest region of India. It is at a distance of 4 km from Alwar city with a small fort, known as the Bala-fort, perched on the highest peak of a west-facing hill slope, and the forest is surrounded by a high wall, since the establishment of Alwar state in 1775 AD (Mayaram, 1968). The undisturbed forest area comprises mainly of two east and west-facing hill slopes opposed to each other with a narrow valley in between which is closed towards the south and opens towards the north with a huge south-facing slope at its mouth. Thus, the undisturbed forest area of about 2 km^2 is surrounded by hills from all sides. The valley is at an altitude of 480 meters and the peaks of surrounding hill slopes are as high as 570 meters above sea level. It is a highly protected forest area since the independence of India in 1947 and represents the typically dry deciduous forest of this region.

The climate is hot and dry with three distinct seasons in a year. The summer season from mid-March to June is extremely hot with the temperature soaring to 47°C, the hot winds that blow from the west during the month of May, and June known as "loo" during this season. The rainy season from July to mid-September with 90% of average annual rainfall (640 mm) occurs during this period and the dry cold winter season from October to February with the temperature dropping to 4°C in December and January. The light showers of rainfall also occur in the winter season (Yadav & Yadav, 2005). The soil is sandy loam with brown colored gravel and shallow along slopes of the hillocks. The soil depth decreases from 14.6 to 10 cm with an increase in the elevation of the hill slope. The soil pH varies from 7.4 to 7.6 in different micro-environments with a slight increase towards the top of hill slopes. The soil moisture contents generally increase with an increase in elevation of slope in the rainy season, however, it was always higher in the valley than that of the hill slope. The organic carbon increased from 0.37 to 1.06 % with an increase in elevation of the hill slope (Yadav & Yadav, 2005).

Methods

The west-facing slope was selected as the study site as it was not a disturbed area while the east-facing slope was disturbed by a road passing through the middle part of the slope. Since the elevation and vegetation of hill slopes are almost uniform in this region of Aravalli mountain range only one site was selected for the study. The biomass of herbaceous vegetation was estimated by harvest method from 2003 to 2004. To evaluate the herbaceous vegetation, the observations were taken from four physiographic locations, *viz*., valley (480 meters), base (500–510 meters), middle (530–540 meters), and top (above 570 meters) of the west-facing hill slope. Ten quadrats of 50 × 50 cm size were laid randomly in each location and herbaceous vegetation was harvested along with soil up to bedrock at quarterly intervals. No plot was harvested more than once. The plants were dug out along with roots. The sandy loam soil with gravel was easily removed from roots and whatever soil remained attached with roots was removed under running water in the laboratory. The plants of different species were separated from each harvested plot and their shoot and roots were also separated. Each fraction was dried to constant weight at 80°C in a hot air oven and its dry weight per unit area was estimated following Misra (1968). The above-ground productivity (ANP) and below-ground productivity (BNP) were computed by the summation of positive changes in the above-ground and below-ground biomass (Singh *et al*., 1975). Similar fractions of biomass obtained from these herbaceous plants growing in the neighborhood of sampling quadrats were air-dried, powdered, and used for nutrient analysis.

The middle part of the slope was gentler than the top and base and represents intermediate micro-environmental conditions, therefore, it was selected for evaluating the standing state of nutrients in this forest. Litter was also collected from each harvested quadrat from the middle part of the hill slope. It was not possible to separate the litter of trees, therefore, it includes the litter of other plants as well. Soil samples were collected separately on each sampling month by digging pits of 10 ×10 ×10 cm^3 near each sampling quadrat. These were oven-dried at 70°C, sieved (2 mm), and used for nutrient analysis. The soil and plant samples were analyzed by the micro-Kjeldahl method (Piper, 1950) for total nitrogen and Olsen's extract, and colorimeter method was followed for the estimation of available phosphorus (Olsen *et al*., 1954).

Dry matter production and its transfer between vegetation components were calculated following the balance sheet approach of Singh and Yadava (1974). The nutrient storage in the standing state was calculated by multiplying concentration (%) of the respective nutrient with standing crop (g m^{-2}). The nutrient concentration per gram dry weight of soil was multiplied by bulk density to obtain its storage in soil. The annual mean nutrient concentration in various components was multiplied with the respective annual net above ground and below ground production values/biomass for estimating the above ground and below ground nutrient uptake. Nutrient transfers from above-ground parts to litter were calculated by multiplying the annual mean nutrient concentration in the litter with quantity. Nutrient release from the litter was calculated by multiplying the annual mean nutrient concentration in the litter with the quantity of litter that mineralized. Similarly, nutrient transfer from below-ground parts to their disappearance was calculated by multiplying the annual mean nutrient concentration is below ground parts (roots) with the quantity of biomass of roots/below the ground part that mineralized during the year. The input and output of the nutrients were calculated from field data.

Results and Discussion

Net Primary Productivity

The average total net primary productivity of herbaceous vegetation was 2.42 t ha^{-1} yr^{-1}, which was higher than that of the Oak forests in the central Himalaya 1.68 to 1.98 t ha^{-1} yr^{-1} (Rawat & Singh, 1988). This may be attributed to the relatively open forest canopy in this forest. However, it was less than that of the tropical deciduous forest of Orissa (4.58 t ha^{-1} yr^{-1}), which may be attributed to high rainfall in that region of India (Joshi *et al*., 1990). The NPP (t ha^{-1} yr^{-1}) of the herbaceous layer was 2.57 at the top, 2.18 at the middle, and 2.41 at the base of the hill slope and 2.50 in the valley (Table 1). The low productivity at the middle of the hill slope may be attributed to the thick canopy cover of the tree species as compared to other locations. This finds support from Yadav and Yadav (2005) who observed a higher density of tree species in the middle part of hill slope than the

Table 1: Quarterly net positive increase (g m^{-2}) in above-ground and root biomass at west-facing hill slope of Bala-fort forest (- denotes quarterly decrease in biomass)

Months	*Above-ground biomass*				*Root biomass*			
	Top	*Mid*	*Base*	*Valley*	*Top*	*Mid*	*Base*	*Valley*
July	179.5	188.7	219.3	82.04	19.09	21.2	20.8	16.07
Oct	48.4	-9.3	-53.3	138.7	6.27	-8.37	-3.35	13.53
Jan	3.7	-5.5	-10.6	-104.1	-6.31	4	1.05	-10.03
Apr	-20.5	-27.3	-30.6	-38.93	-5.01	4.08	-0.3	-10.81
Total positive increment (g m^{-2} yr^{-1})	231.6	188.7	219.3	220.7	25.36	29.28	21.85	29.6

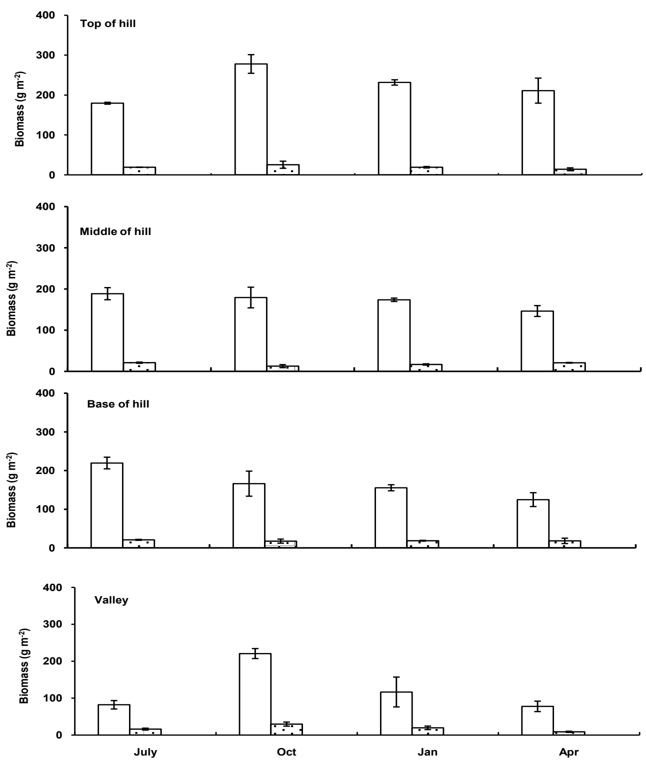

Fig. 1: Seasonal variation in the biomass of herbaceous vegetation with increase in altitude of hill slope in Bala-fort forest

other three locations in this forest. This is in agreement with Sagar *et al*. (2012) who observed that tree canopy, light intensity, and soil moisture influence the herbaceous vegetation in tropical dry deciduous forests. The peak of NPP was observed in July at four locations, however, the biomass accumulation increased considerably at the base and top of the slope till October. This may be attributed to the open canopy and availability of high soil moisture in both the sites till October. The observations suggest that the standing crop of the herbaceous layer exhibits distinct seasonal variations and is highly influenced by the elevation of hill slopes.

The above-ground biomass was the highest in October in the valley (221 g m^{-2}) and at the top (278 g m^{-2}), whereas it was the highest in July at the base (219 g m^{-2}) and the middle (189 g m^{-2}) of the hill slope (Fig. 1). The maximum herbaceous biomass in July and October may be due to the rainfall that occurs from July to mid-September. Singh and Yadava (1974), Karunaichamy and Paliwal (1995), and Meenakshisundaravalli and Paliwal (1997) have also reported a positive relationship between above ground biomass and the amount of monthly rainfall during the annual cycle of tropical grassland. The standing crop of the herbaceous layer exhibited a decline in seasonal variation with an increase in elevation of the hill slope. It may be attributed to different kinds of species dominating at varying elevations on the hill slope. Although the lowest above-ground biomass was recorded in April (77 gm^{-2}) in the valley, but it was 211 gm^{-2} at the top of the hill. The sufficient amount of above ground biomass in April on the top of slope may be due to the growth of perennial herbs such as, *A. aspera* and *Peristrophe paniculata*. The below ground biomass was maximum in July and October in four locations which declined from October onwards (Fig. 1).

These observations indicate that maximum biomass to roots is allocated at the beginning of the growing period. The biomass allocated to roots was 9.9, 13.4, 9.1, and 11.8 percent of total biomass at the top, the middle, the base of the hillslope, and in the valley, respectively. This suggests that herbaceous species allocated very less amount of biomass to roots, as sufficient soil moisture was available during the growing period, which coincides with the rainy season. However, these plants allocated about 90 percent of their biomass to above-ground parts in response to severe competition for light and to maximize seed production for the perpetuation of their populations.

The above-ground biomass of individual species showed high variation in different locations and with time. Out of 20 herbaceous species growing at the top of the hill slope, *A. aspera* exhibited maximum biomass g m^{-2} (130) in April, followed by *Commelina benghalensis* (66) in October (Table 2). The other important species were *Bidens biternata* (39) and *P. paniculata* (39). These species also showed maximum below-ground biomass, although it was highest in July like other herbaceous species. In the middle of the slope, out of 20 herbaceous species, *A. aspera* showed maximum biomass (85) in January followed by *Physalis minima* (32), *C. benghalensis* (28) in July, and *B. biternata* (31) in April (Table 3). *A. aspera* also produced a maximum below-ground biomass (11) in July at this location. However, at the base of the slope, out of 15 herbaceous species, *B. biternata* produced maximum above-ground biomass (175) in July followed by *Abutilon indicum* (26), *Sida veronicifolia* (36) in October, and *Vernonia cinerea* (43) in April. These species also exhibited a maximum below ground biomass at this site (Table 4). Out of 17 herbaceous species present in the valley, *C. aestuans* showed maximum above-ground biomass (41) in October and *A. indicum* (25), and *B. biternata* (28) in January.

Table 2: Quarterly above-ground and below-ground biomass (g m^{-2}) at the top of west-facing hill slope of Bala-fort forest (- denotes species is absent ± S.E.)

	Above-ground biomass				*Blow-ground biomass*			
Name of species	*July*	*October*	*January*	*April*	*July*	*October*	*January*	*April*
A. aspera	69.6 ± 8.6	88.1 ± 22.2	74.4 ± 3.7	129.8 ± 39.1	8.5 ± 0.8	4.8 ± 1.1	6.2 ± 1.4	7.6 ± 2.9
B. biternata	-	39 ± 28	12.5 ± 12.5	32.1 ± 32.1	-	2.9 ± 1.6	1.1 ± 1.1	1.3 ± 1.3
B. ramosa	9.8 ± 5.2	6.2 ± 3.2	15.2 ± 15.2	-	0.6 ± 0.3	0.3 ± 0.2	1 ± 1	-
Cardiospermum helicacabum	1.4 ± 0.7	-	4.57 ± 4.57	-	0.2 ± 0.1	-	0.4 ± 0.4	-
C. benghalensis	55 ± 27.6	65.9 ± 31.8	12.1 ± 12.1	-	5.3 ± 2.7	2.9 ± 1.2	1 ± 1	-
Commelina forskalei	30.2 ± 30.2	2.6 ± 2.6	-	-	2.4 ± 2.4	0.3 ± 0.3	-	-
C. aestuans	-	5.6 ± 5.6	11.6 ± 1.6	-	-	0.4 ± 0.4	0.8 ± 0.8	-
Desmodium repandum	1 ± 1	-	2.85 ± 2.85	-	0.1 ± 0.1	-	0.3 ± 0.3	-
Dichanthium annulatum	-	-	-	-	-	-	-	-
Hibiscus ovalifolius	4.6 ± 4.6	4.1 ± 4.1	-	-	0.6 ± 0.6	0.2 ± 0.2	-	-
Ipomoea dichora	1.7 ± 1.7	6.2 ± 6.2	1.49 ± 1.49	-	0.3 ± 0.3	0.2 ± 0.2	0.4 ± 0.4	-
Ipomoea muricata	4.4 ± 2.3	-	-	-	1.0 ± 0.5	-	-	-
P. paniculata	-	20.2 ± 20.2	39.3 ± 21.2	16.7 ± 16.7	-	8.8 ± 8.8	2.5 ± 2.5	1.8 ± 1.8
Phyllanthus fraternus	1.6 ± 1.4	-	15.28 ± 7.7	-	0.2 ± 0.1	-	0.7 ± 0.4	-
Physalis minima	0.85 ± 0.8	-	13.3 ± 13.3	-	0.1 ± 0.1	-	0.8 ± 0.8	-
Rhynchosia minima	-	3.1 ± 3.1	-	-	-	1.2 ± 1.2	-	-
Sclerocarpus africanus	-	15.2 ± 15.2	8.41 ± 8.41	-	-	1.1 ± 1.1	0.8 ± 0.8	-
S. veronicifolia		-	-	21.8 ± 21.8	-	-	-	2.4 ± 2.4
Tridax procumbens	-	-	5.31 ± 5.31	-	-	-	1.2 ± 1.2	-
V. cinerea	-	22.1 ± 13.1	15.2 ± 15.2	11.6 ± 11.6	-	2.5 ± 1.2	1.9 ± 1.9	0.9 ± 0.9

Table 3: Quarterly above-ground and below-ground biomass (g m^{-2}) at the middle of west-facing hill slope of Bala-fort forest (- denotes species is absent ± S.E.)

	Above-ground biomass				*Blow-ground biomass*			
Name of species	*July*	*October*	*January*	*April*	*July*	*October*	*January*	*April*
A. aspera	75 ± 26.3	39 ± 27.4	85.4 ± 13.1	47.7 ± 4.9	11.2 ± 1.5	2.7 ± 1.9	6.9 ± 1.2	4.1 ± 1
A. indicum	-	1.6 ± 1.6	-	-	-	0.3 ± 0.3	-	-
Acalypha indica	-	1.8 ± 1.8	14.4 ± 7.4	-	-	0.1 ± 0.1	1.4 ± 0.8	-
B. biternata	22.8 ± 1	28.9 ± 13.1	19.3 ± 9.7	30.9 ± 8.1	2.1 ± 0.1	1.6 ± 0.5	2.2 ± 1.1	8 ± 2.4
Cardiospermum helicacabum	-	-	-	-	-	-	-	-
C. benghalensis	28.3 ± 8.2	6.2 ± 6.2	13.2 ± 6.6	-	1.8 ± 0.6	0.4 ± 0.4	0.7 ± 0.4	-
Commelina forskalei	-	-	-	-	-	-	-	-
C. aestuans	3.8 ± 3.8	3.8 ± 3.8	13.7 ± 7.2	7.8 ± 4.1	0.4 ± 0.4	0.2 ± 0.2	0.9 ± 0.5	0.5 ± 0.3
Desmodium repandum	1.8 ± 1.8	-	-	-	0.3 ± 0.3	-	-	-
Dichanthium annulatum	14.8 ± 14.8	23.8 ± 12.0	4.3 ± 2.5	-	2.1 ± 2.1	1.8 ± 0.9	0.8 ± 0.4	-
Dipteracanthus prostratus	-	1.2 ± 1.2	-	-	-	0.3 ± 0.3	-	-
Hibiscus ovalifolius	5.01 ± 3.0	-	-	-	0.6 ± 0.3	-	-	-
Ipomoea dichora	2.8 ± 2.8	6.9 ± 6.9	-	-	0.2 ± 0.2	0.2 ± 0.2	-	-
Ipomoea muricata	0.9 ± 0.9	3.2 ± 3.2	-	-	0.2 ± 0.2	0.2 ± 0.2	-	-
Phyllanthus fraternus	1.5 ± 1.5	-	-	-	0.2 ± 0.2	-	-	-
Physalis minima	32.1 ± 16.1	-	5.7 ± 5.7	-	2.3 ± 1.2	-	0.6 ± 0.6	-
Sida ovata	-	21.2 ± 21.2	4.8 ± 4.8	18.7 ± 9.4	-	1.7 ± 1.7	0.8 ± 0.8	2.7 ± 1.4
S. veronicifolia	-	28.2 ± 21.2	4.6 ± 4.6	-	-	1.7 ± 1.4	0.8 ± 0.8	-
Triumfetta rhomboidea	-	9.5 ± 9.5	-	-	-	1.4 ± 1.4	-	-
V. cinerea	-	4.1 ± 4.1	8.4 ± 6.3	41.6 ± 24	-	0.3 ± 0.3	1.7 ± 1.2	5.7 ± 2.9

However, these species also produced maximum below-ground biomass in October (Table 5). These observations suggest that *A. aspera* is a dominant species at the top and the middle part of the hill slope, whereas *B. biternata* is dominant at the base of the slope, while *C. aestuans* remains dominant in the valley of this forest. Out of the herbaceous species present in the study site, 29 species contributed annually to more than 1 g m^{-2} biomass on the hill slope of the Bala-fort forest. The contribution among these species was *B. biternata* (54%) and *A. aspera* (44%), followed by *C. benghalensis*, *V. cinerea*, *C. aestuans*, *P. paniculata*, and *B. biternata* (about 10 percent each) (Table 6).

Table 4: Quarterly above-ground and below-ground biomass (g m^{-2}) at the base of west-facing hill slope of Bala-fort forest (- denotes species is absent ± S.E.)

	Above-ground biomass				*Blow-ground biomass*			
Name of species	*July*	*October*	*January*	*April*	*July*	*October*	*January*	*April*
A. aspera	7.1 ± 1.1	-	-	-	0.5 ± 0.1	-	-	-
A. indicum	0.4 ± 0.4	26.3 ± 21	15.5 ± 15.5	-	0.1 ± 0.1	6.2 ± 4.6	2.8 ± 2.8	-
Acalypha indica	11.1 ± 0.6	4.6 ± 1.1	-	-	1.3 ± 0.1	0.5 ± 0.1	-	-
B. biternata	175.3 ± 17.9	38.2 ± 11.9	54.9 ± 2.7	10.9 ± 10.9	16.2 ± 01	1.9 ± 0.5	3.9 ± 0.1	1.2 ± 1.2
Commelina forskalei	4.3 ± 4.3	-	-	-	0.2 ± 0.2	-	-	-
C. aestuans	-	10.3 ± 9.1	4.9 ± 0.7	11.8 ± 8.2	-	0.6 ± 0.5	0.9 ± 0.1	1.1 ± 0.7
Desmodium repandum	1.9 ± 1.5	-	-	-	0.1 ± 0.1	-	-	-
Dichanthium annulatum	-	11.7 ± 11.7	-	23.6 ± 13.9	-	1.9 ± 1.9	-	5.7 ± 3.1
P. paniculata	-	-	23.3 ± 12.3	27.4 ± 18.3	-	-	2.9 ± 1.5	3.6 ± 2.5
Phyllanthus fraternus	5.8 ± 0.3	-	0.8 ± 0.8	-	0.6 ± 0.2	-	0.2 ± 0.2	-
Physalis minima	13.3 ± 3.3	-	4.9 ± 4.9	-	1.8 ± 0.3	-	0.9 ± 0.9	-
Sida ovata	-	16.4 ± 8.6	9.7 ± 4.9	8.6 ± 4.7	-	1.5 ± 0.8	1.3 ± 0.7	1.0 ± 0.5
S. veronicifolia	-	36.3 ± 19.3	-	-	-	2.6 ± 1.4	-	-
Triumfetta rhomboidea	-	7.6 ± 6.3	16.2 ± 8.4	-	-	0.7 ± 0.6	2.1 ± 1.1	-
V. cinerea	-	14.7 ± 7.3	25.1 ± 12.6	42.8 ± 14.1	-	1.7 ± 0.9	3.6 ± 2.2	5.6 ± 3.8

Table 5: Quarterly above-ground and below-ground biomass (g m^{-2}) in the valley of Bala-fort forest (- denotes species is absent ± S.E.)

	Above-ground biomass				*Blow-ground biomass*			
Name of species	*July*	*October*	*January*	*April*	*July*	*October*	*January*	*April*
A. aspera	16.4 ± 6.1	-	3.76 ± 3.76	-	3.1 ± 0.9	-	0.5 ± 0.5	-
A. indicum	13.6 ± 7.8	23.2 ± 3.1	25.4 ± 14.8	10.8 ± 10.8	0.2 ± 0.2	7.3 ± 1.7	4.5 ± 2.1	1.5 ± 1.5
Acalypha indica	1.5 ± 1.5	-	1.04 ± 1.04	-	2.7 ± 1.4	-	0.4 ± 0.4	-
B. biternata	9.4 ± 4.8	87.4 ± 6.8	28.4 ± 17.6	18.8 ± 9.6	1.7 ± 0.9	12.3 ± 8.6	2.6 ± 1.3	2.3 ± 1.2
C. benghalensis	4.6 ± 4.6	2.3 ± 2.3	-	-	1.2 ± 1.2	0.3 ± 0.3	-	-
C. aestuans	6.8 ± 4.8	40.6 ± 9.5	3.9 ± 2.5	12.1 ± 1.6	1.4 ± 1.1	3.4 ± 0.8	1.6 ± 1.2	1.4 ± 0.1
Cynodon dactylon	19.5 ± 10.3	18.1 ± 8.1	17.7 ± 11.9	16.8 ± 8.6	4.2 ± 2.2	2.4 ± 2.4	3.6 ± 2.2	1.5 ± 0.9
Desmodium repandum	1.5 ± 1.5	-	-	-	0.2 ± 0.2	-	-	-
Dipteracanthus prostratus	-	-	0.91 ± 0.91	-	-	-	0.4 ± 0.4	-
Galactia tenuiflora	-	4.6 ± 4.6	-	-	-	0.7 ± 0.7	-	-
Leucas aspera	2.6 ± 2.6	27.2 ± 17	4.03 ± 2.5	-	0.3 ± 0.3	1.1 ± 0.6	1.3 ± 0.9	-
P. paniculata	-	-	-	9.4 ± 9.4	-	-	-	1.1 ± 1.1
Physalis minima	-	-	0.81 ± 0.81	-	-	-	0.3 ± 0.3	-
Pupalia lappacea	-	-	18.9 ± 9.8	-	-	-	2.1 ± 1.1	-
S. veronicifolia	-	9.2 ± 9.2	-	4.2 ± 4.2	-	0.8 ± 0.8	-	0.5 ± 0.5
Triumfetta rhomboidea	6.3 ± 3.4	8.2 ± 8.2	-	-	1.4 ± 0.8	1.2 ± 1.2	-	-
V. cinerea	-	-	11.7 ± 11.7	5.6 ± 5.6	-	-	2.5 ± 2.5	0.4 ± 0.4

Litter Biomass

Since the litter of previous year and fresh litter in harvested plots were mixed so it was not possible to precisely separate the litter of herbs from that of woody species. Therefore, litter biomass includes the litter of woody, as well as, herbaceous species.

Table 6: Contribution of important* species to total net above-ground primary Production of west-facing hill slope of Bala-fort forest

Species	*Peak biomass (g m^{-2})*
Brachiaria ramosa (L.) Stapf.	175.3
Achyranthes aspera L.	129.8
Commelina benghalensis L.	65.9
Vernonia cinerea (L.) Less.	42.8
Corchorus aestuans L.	40.6
Peristrophe paniculata (Forsk.) Brummitt	39.3
Bidens biternata (Laur.) Merr. & Sherff.	39.0
Sida veronicifolia Lamk.	36.3
Physalis minima L.	32.1
Commelina forskalei Vahl.	30.2
Leucas aspera (Willd.) Spreng.	27.2
Abutilon indicum (L.) Sweet.	26.3
Dichanthium annulatum (Forsk.) Stapf.	23.8
Sida ovata Forsk.	21.2
Cynodon dactylon (L.) Pers.	19.5
Pupalia lappacea (L.) Juss.	18.9
Triumfetta rhomboidea Jacq.	16.2
Phyllanthus fraternus Webster	15.3
Sclerocarpus africanus Jacq. ex Murr.	15.2
Acalypha indica L.	14.4
Ipomoea dichora Roem. & Schult.	6.9
Tridax procumbens L.	5.3
Hibiscus ovalifolius (Forsk.) Vahl.	5. 1
Galactia tenuiflora (Klein ex Willd.) Wight & Arm.	4.6
Cardiospermum helicacabum L.	4.6
Ipomoea muricata (Linn.) Jacq.	4.4
Rhynchosia minima (L.) DC.	3.1
Desmodium repandum (Vahl.) DC.	2.9
Dipteracanthus prostratus (Poir.) Nees	1.2

*Important species defined as those which contribute ≥ 1 g m^{-2} to above ground net primary production (ANP).

The standing crop of litter biomass (g m^{-2}) was the lowest in July, i.e., 82, 117, 75, and 113 at the top, the middle, the base of the hillslope, and in the valley, respectively (Fig. 2). It began to increase from July onwards attaining the peak in April, i.e., 718, 655, 449, and 283 at the top, the middle, the base of the slope, and in the valley, respectively. The low standing crop of litter at the base and in the valley may be due to loss of organic matter through high runoff water in these sites. The accumulation of a large amount of litter biomass till April in four locations suggests that the rate of decomposition is very slow with the decline in soil moisture and low-temperature conditions in winter, and following hot and dry summer season. This finds support from Upadhyay and Singh (1989) who reported that rainfall and temperature play a significant role in the decomposition of litter in forest ecosystems.

Nutrient Concentration in Biomass Components

The average concentration (percentage) of total nitrogen and available phosphorus was 1.61 and 0.32, respectively, in the above-ground biomass and 1.58 and 0.34, respectively, in the litter. The values were lower in below-ground biomass, i.e., 1.44 and 0.28 (Table 7). It is an interesting observation that the concentration of total nitrogen decreased from 1.9% in July to 1.4% in April in the above-ground biomass. This may be due to the decrease in the growth of the herbaceous layer from October

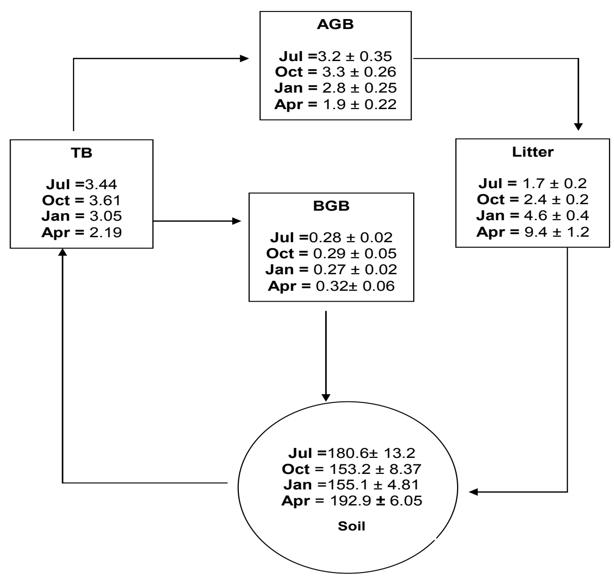

Fig. 2: The standing state of total Kjeldahl nitrogen (g m^{-2}) in herbaceous biomass, litter, and soil in the Bala-fort dry deciduous forest (TB = total herbaceous biomass; AGB = above-ground biomass; BGB = below-ground biomass)

Table 7: Average percentage of nitrogen, phosphorus, and storage in the plant components of herbaceous vegetation and forest floor litter at Bala-fort forest (± S.E)

Components	*Nutrient concentration (%)*		*Nutrient concentration (kg ha^{-1})*	
	Nitrogen	*Phosphorus*	*Nitrogen*	*Phosphorus*
Above-ground biomass	1.61 ± 0.1	0.32 ± 0.02	27.8 ± 3.2	5.6 ± 0.6
Below-ground biomass	1.44 ± 0.07	0.28 ± 0.03	2.9 ± 0.1	0.5 ± 0.1
Litter	1.58 ± 0.1	0.34 ± 0.03	44.5 ± 17.4	10.1 ± 3.9
Mean	1.55 ± 0.06	0.32 ± 0.02	75.6	16.2

onwards. Interestingly, a reverse trend was prominent for below-ground biomass where nitrogen concentration increased from 1.3% in October to 1.6% in April, which indicated that nitrogen is retained/accumulated. Before the litterfall occurred, the nitrogen, a vital element, and which is in causality in dry climate was translocated into below-ground parts. This is a strong strategy of arid and semi-arid species for the conservation of nitrogen. Among the soil and biomass components, the maximum concentration of nitrogen and phosphorus was 44.5 and 10.1 kg ha^{-1} in the litter. This means that about 64 percent of the total nutrients of biomass is present in the litter. In the case of litter, nitrogen concentration was the highest in April (9 g m^{-2}) and then declined rapidly to the lowest level (1.7 g m^{-2}) by July. This trend is strongly related to a high decomposition rate of litter in rainy season. Increased concentration October onwards may be due to the fresh litterfall and senescence of herbaceous vegetation.

The standing state of nitrogen in the soil and biomass components indicated that the concentration of nitrogen was very high in the soil as compared to that in biomass components (Fig. 2). Phosphorus also followed the same trend but almost 50 percent of total phosphorus present in the soil, was recycled through the herbaceous vegetation and litter. With the senescence of vegetation, the standing state of these two elements decreased in living biomass and started increasing in soil and forest floor litter attaining a peak in the summer season. This interesting observation strongly indicated that a sufficient amount of nutrients are retained in the litter during the dry summer period. The storage of large quantities of nitrogen and phosphorus in litter and soil organic matter may be a useful mechanism for the conservation of these nutrients against their loss through leaching or soil erosion in these tropical dry deciduous forests. These results are also in agreement with Karunaichamy and Paliwal (1995) who reported that 95% of the nutrients remain in root debris, organic matter, and other soil fractions in the tropical grazing land ecosystem in southern India. The maximum concentration of nitrogen in the soil (193 g m^{-2}) was in April which declined sharply to 153 g m^{-2} by October, and then remained unchanged till the following January. This may be due to the immobilization of these elements by micro-organisms (Upadhayay & Singh, 1989).

The concentration of nitrogen in the above-ground biomass was 3.2 g m^{-2}, which decreased slowly till the following January and reached the lowest level (1.9 g m^{-2}) by April. However, only about 9 percent of nitrogen present in herbaceous biomass was allocated to below-ground biomass, which remained almost unchanged throughout the year. In contrast to nitrogen concentration, phosphorus concentration in the herbaceous layer was the lowest in July and became the highest by October in all biomass components (Fig. 3). It increased from 0.29% in (April) to 0.38% in October in the above-ground biomass, 0.23% in July to 0.34% in January in the below-ground biomass, and from 0.25% in July to 0.38% in April in the litter component.

The increase may be due to its enhanced availability through a high rate of mineralization and microbial activity during this period. This finds support from Singh *et al.* (1989) who suggested that the microbial biomass release nutrients rapidly in the rainy season in the tropical dry deciduous forest. McGarth *et al.* (2000) also observed that phosphorus availability was lowest in bare mineral soils. However, in litter components, it may be due to the addition of fresh litter from September onwards. Though the concentration of phosphorus decreased from October to January in the above-ground biomass, but an almost negligible change was observed in below ground biomass and its constant concentration in litter from October to April suggests that retranslocation of phosphorus does not take place during leaf fall in this forest. Average standing state (kg ha^{-1}) of nitrogen and phosphorus was 27.8 and 5.6, respectively, in the above ground biomass, whereas the corresponding values for below ground biomass were 2.9 and 0.5, respectively (Table 7). It indicates that the herbaceous vegetation allocates ten times more nutrients to the above ground biomass than to below ground biomass.

Annual Uptake, Transfer, and Release of Nutrients

The annual uptake of nitrogen was 3.84 g m^{-2}, while that of phosphorus was 0.76 g m^{-2} by the herbaceous vegetation of the Bala-fort tropical dry deciduous forest (Fig. 4). Out of this, about 90% nitrogen and phosphorus were allocated to above-ground parts whereas only 10% were transferred for the growth of below-ground parts. In live shoots, 3.5 and 0.65 g m^{-2} nitrogen and phosphorus were allocated, respectively, whereas 0.38 and 0.07 g m^{-2} nitrogen and phosphorus, respectively, were transferred to the roots annually. The amount of nitrogen and phosphorus added to the forest floor from the herbaceous vegetation was 1.34 and 0.27 g m^{-2}, respectively. The amount of nitrogen (4.49 g m^{-2}) and phosphorus (1.01 g m^{-2}) in the forest floor litter are due to the accumulated litter of the previous year and it also included the litterfall of the woody vegetation. These results are also in agreement with Karunaichamy and Paliwal (1995) who reported that 95%

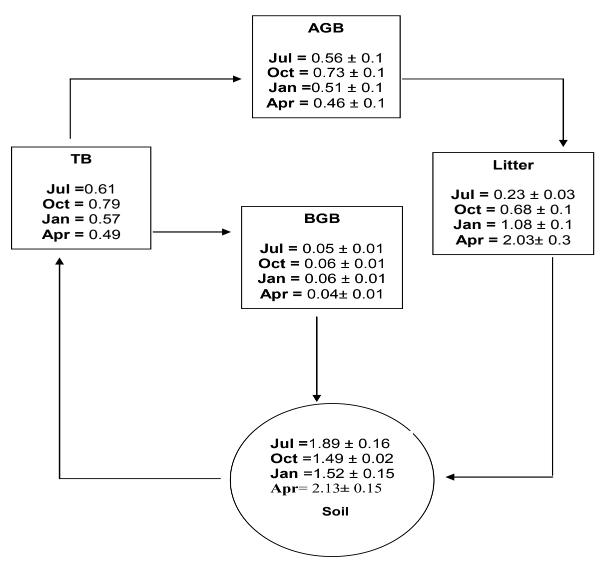

Fig. 3: Standing state of phosphorus (g m^{-2}) in herbaceous biomass, litter, and soil in the Bala-fort dry deciduous forest (TB = total herbaceous biomass; AGB = above-ground biomass; BGB = below-ground biomass)

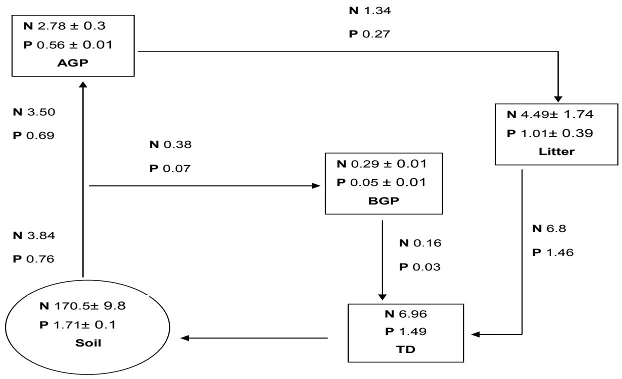

Fig. 4: Uptake, transfer, and release of nitrogen (TKN) and phosphorus in Bala-fort forest in Alwar, Rajasthan; Values in compartments are mean standing crop of nitrogen and phosphorus in g m^{-2} and those on an arrow are net annual flux rates in g m^{-2} yr^{-1} (AGP = above-ground part; BGP = below ground part; TD = total disappearance)

of the nutrients remain in root debris, organic matter, and other soil fractions in the tropical grazing land ecosystem in southern India. A considerable amount of nitrogen (6.8 g m^{-2}) and phosphorus (1.46 g m^{-2}) were added to the soil through decomposition of below-ground biomass. Hence, a large amount of nitrogen and phosphorus were returned to the soil annually, which contributes to the high concentration of these nutrients in the soil of the Bala-fort forest. On an annual basis, nitrogen is taken up in a higher quantity (173 kg ha^{-1} yr^{-1}) than phosphorus (31 kg ha^{-1} yr^{-1}). The rate of release is relatively higher for phosphorus 6.08 kg ha^{-1} yr^{-1} (19%) than nitrogen 21.54 kg ha^{-1} yr^{-1} (16%). Consequently, more nitrogen was retained in biomass (115.6 kg ha^{-1} yr^{-1}) (84%) than phosphorus (25.3 kg ha^{-1} yr^{-1}) (81%).

Conclusions

The nine months dry period in a year and frequent droughts lead to the accumulation of a large amount of forest floor litter biomass in this tropical dry deciduous forest. The storage of large quantities of nitrogen and phosphorus in litter and soil organic matter may be a useful mechanism for the conservation of these nutrients. The herbaceous vegetation which thrives only in rainy season play important role in the conservation of nutrients through absorption by roots and by reducing the loss of nutrients with runoff water during heavy rains. However, the human disturbance which adversely affects the soil layer may lead to soil erosion consequently reducing the growth of the herbaceous layer. Hence, it may be suggested that the rich plant diversity of this forest ecosystem may be conserved *in situ* by reducing disturbances of biomass lopping and grazing.

Acknoledgements

The financial assistance received from the University Grants Commission, New Delhi, as a major research project to Atar Singh Yadav is gratefully acknowledged. The authors are grateful to Professor S. K. Barik, Department of Botany, North-Eastern Hill University, Shillong, for a critical review of the manuscript.

References

Das, D.K., Chaturvedi, O.P., Mandal, M.P. and Kumar, R. 2008. Effect of tree plantations on biomass and primary productivity of herbaceous vegetation in eastern India. *Tropical Ecology* **49**:95-101.

Elliott, K.J., Vose, J.M., Knoepp, J.D., Clinton, B.D. and Kloeppel, B.D. 2015. Functional role of the herbaceous layer in eastern deciduous forest ecosystems. *Ecosystems* **18**:221-236.

Joshi, S.K., Pati, D.P. and Behera, N. 1990. Primary production of herbaceous layer in a tropical deciduous forest in Orissa, India. *Tropical Ecology* **31**:73-83.

Karunaichamy, K.S.T.K. and Paliwal, K. 1995. Nutrient dynamics of tropical grazing land ecosystem in southern India. *Tropical Ecology* **36:**227-235.

Mayaram 1968. *Rajasthan District Gazetteers, Alwar*. Jaipur: Bharat Printers, pp. 709-712.

McGrath, D.A., Comerford, N.B. and Duryea, M.L. 2000. Litter dynamics and monthly fluctuation in soil phosphorus availability in an Amazonian agroforest. *Forest Ecology and Management* **131**:167-181.

Meenakshisundaravalli, V. and Paliwal, K. 1997. Dry matter production and nitrogen dynamics in the semi-arid grazing land of Madurai, India. *Tropical Ecology* **38:**81-86.

Misra, R. 1968. *Ecology Work Book*. New Delhi: Oxford and IBH Publishing Co.

Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. 1954. Estimation of available phosphorus in soils by extraction with extraction with Sodium bicarbonate. U.S. Department of Agriculture Circular **939**:1-19.

Pandey, H.N. and Singh, R.N. 1990. Nitrogen storage and cycling in early stages of grassland community at Varanasi, India. *Tropical Ecology* **31**:75-81.

Piper, S.C. 1950. Plant and Soil Analysis. Adelaide, Australia: The University of Adelaide.

Pradhan, G.B. and Dash, M.C. 1984. Seasonal variation in plant biomass and net primary productivity of a savanna type hill ecosystem of Sambalpur, India. *Tropical Ecology* **25:**172-178.

Sagar, R., Pandey, A. and Singh, J.S. 2012. Composition, species diversity and biomass of the herbaceous community in dry tropical forest of northern India in relation to soil moisture and light intensity. *The Environmentalist* **32**:485-493.

Rawat, Y.S. and Singh, J.S. 1988. Structure and function of oak forests in Central Himalaya. **II**. Nutrient dynamics. *Annals of Botany* **62:**413-427.

Sharma, K.P. and Upadhayaya, B.P. 2002. Phytosociology, primary production and nutrient retention in herbaceous vegetation of the forestry arboretum on the Aravalli hills at Jaipur. *Tropical Ecology* **43:**325-335.

Singh, J.S., Lauenroth, W.K. and Steinhorst, R.K. 1975. Review and assessment of various techniques for estimating net aerial primary production in grassland from harvest data. *Botanical Review* **41:**181-232.

Singh, J.S. and Yadava, P.S. 1974. Seasonal variation in composition, plant biomass and net primary productivity of a tropical grassland at Kurukshetra, India. *Ecological Monographs* **44:**351-376.

Singh, J.N. and Mudgal, V. 2000. Assessment of mineral content of tree leaf litter of Nokrek biosphere reserve and its impact on soil properties. *Tropical Ecoloy* **41**:225-232.

Singh, K.P. and Singh, R.P. 1980. Biomass and net production of herbaceous layer in tropical dry deciduous forest at Varanasi. *Tropical Ecology* **21:**47-58.

Singh, J.S., Raghubanshi, A.S., Singh, R.S. and Srivastava, S.C. 1989. Microbial biomass acts as a source of plant nutrients in dry tropical forest and savanna. *Nature* **338**:499-500.

Singh, R., Sagar, R., Srivastava, P., Singh, P. and Singh, J.S. 2017. Herbaceous species diversity and soil attributes along a forest savanna-grassland continuum in a dry tropical region. *Ecological Engineering* **103**:226-235

Upadhayay, V.P. and Singh, J.S. 1989. Patterns of nutrient immobilization and release in decomposing forest litter in Central Himalaya, India. *Journal of Ecology* **77:**127-146.

Vyas, L.N. and Vyas, N.L. 1978. Net primary production of *Apluda* community on Aravalli hills at Udaipur. *In:* Singh, J.S. and Gopal, B. (Eds.), Glimpses of Ecology, Jaipur: International Scientific Publications, pp. 111-124.

Yadav, A.S. and Yadav, R.K. 2005. Plant community structure of the Bala-fort forest in Alwar, Rajasthan. *International Journal of Ecology and Environmental Sciences* **31**:109-117.