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Forest structure, diversity and soil properties in a dry tropical forest in Rajasthan, Western India

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Abstract. Structure, species composition, and soil properties of a dry tropical forest in Rajasthan Western India, were examined by establishment of 25 plots. The forest was characterized by a relatively low canopy and a large number of small-diameter trees. Mean canopy height for this forest was 10 m and stands contained an average of 995 stems ha^{-1} ($\geq$ 3.0 cm DBH); 52% of those stems were smaller than 10 cm DBH. The total basal area was 46.35 m^2ha^{-1}, of which *Tectona grandis* L. contributed 48%. The forest showed high species diversity of trees. 50 tree species ($\geq$ 3.0 cm DBH) from 29 families were identified in the 25 sampling plots. *T. grandis* (20.81%) and *Butea monosperma* (9%) were the dominant and subdominant species in terms of importance value. The mean tree species diversity indices for the plots were 1.08 for Shannon diversity index (H'), 0.71 for equitability index (J') and 5.57 for species richness index (S'), all of which strongly declined with the increase of importance value of the dominant, *T. grandis*. Measures of soil nutrients indicated low fertility, extreme heterogeneity. Regression analysis showed that stem density and the dominant tree height were significantly correlated with soil pH. There was a significant positive relationship between species diversity index and soil available P, exchangeable K^+, Ca^{2+} (all p values < 0.001) and a negative relationship with N, C, C:N and C:P ratio. The results suggest that soil properties are major factors influencing forest composition and structure within the dry tropical forest in Rajasthan.
Keywords dry tropical forest, diversity index, species composition, soil nutrient, soil-vegetation relation.

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Introduction

Tropical forests are often referred to as one of the most species diverse terrestrial ecosystems, and generate a variety of natural resources to help sustain the livelihood of local communities (Kumar et al. 2006). Trees form the major structural and functional basis of tropical forest ecosystems and can serve as robust indicators of changes and stresses at the landscape scale. In Rajasthan, the hilly topography in Aravally mountain ranges provides a wide variety of microhabitats which support rich biodiversity of plant species (Nirmal Kumar et al. 2010b).The vegetation communities of tropical dry forests have been recognized as comprising some of the most endangered ecosystems in the tropics (Hoekstra et al. 2005). However, many tropical forests are under great anthropogenic pressure and require management intervention to maintain the overall biodiversity, productivity and sustainability. Understanding species diversity and distribution patterns is important for helping managers evaluate the complexity and resources of these forests (Nirmal Kumar et al. 2000, 2001, 2002, Yadav & Yadav 2005). Species diversity and the soil physicochemical and biological properties of bamboo forests under different stand structures or different management intensities have been studied (Arunachalam & Arunachalam 2002), with the goal of biodiversity maintenance and soil improvement, as these are two key management objectives to permit sustainable forestry (Lindenmayer et al. 2000)

Dry tropical forests dominated by deciduous species (*Tectona grandis* L., *Butea monosperma*) are widely distributed in dry tropical region of Western India. The basic feature of this forest is low canopy and high diversity of tree species (Nirmal Kumar et al. 2010b). In dry tropical forest ecosystems, soil nutrients play an important role in the formation of plant communities, their species and structural diversity, thus soil conservation has fundamental significance for biodiversity conservation and sustainable land use (Wang et al. 2004). We are unaware of any study that has documented the relationship between structure, forest composition and soil properties in this area. If repeated disturbance is the primary factor for development of this peculiar structure of the Rajasthan dry tropical forest, then one should find a relatively weak relationship between forest vegetation and soil properties.

The present study is aimed at determining the extent to which soil properties influence forest composition structure in the dry tropical forest, Rajasthan, western India.

Materials and methods

Study area

The site was located between 23°3’ – 30°12’N longitude and 69°30’ - 78°17’E latitude in a tropical dry deciduous forest in the Aravally range of Rajasthan, India (Fig. 1). There are three seasons per year: winter (November to February), summer (April to mid-June), and a rainy season (mid-June to mid-September). The months of October and March are transitional periods and are known as autumn and spring, respectively. The climate of Rajasthan is tropical with a maximum of 46.3° C and a minimum of 28.8° C during summers. Winters are a little cold with the maximum temperature rising to 26.8° C and the minimum dropping to 2.5° C. The average annual rainfall of the area is 610 mm. Approximately 90% of the rainfall is received from June to September. The average maximum temperature ranges from 42.3 to 46° C and a minimum of 28.8° C during summers and minimum dipping to 26 to 2.5° C, respectively. The soil is alluvial, yellowish brown to deep medium black and loamy with rocky beds. According to the classification of Champion and Seth (1968), the present forest area is categorized under group 5A/(1b) as ‘tropical dry deciduous forest’.

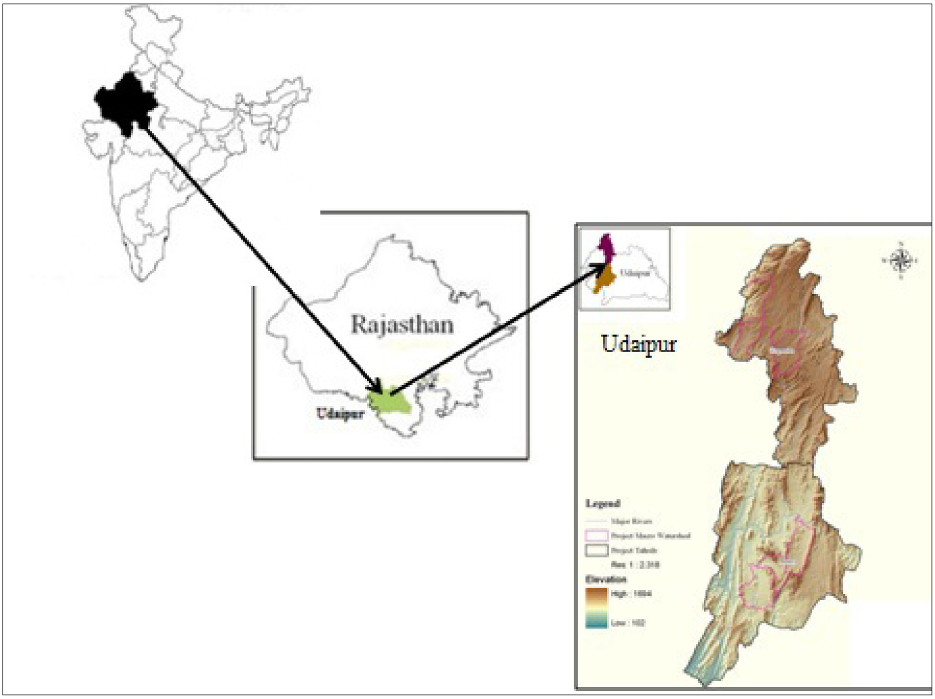

Figure 1 Location of study area

Vegetation and soil sampling

A total of 25 plots with an area of 20 m × 20 m in size, were established in year 1990 in the forest stands which have been undisturbed by human activities. All trees with diameter at breast height (DBH) larger than 3.0 cm in each plot were numbered, and identified to species. Their DBHs were recorded. Height was estimated for all trees using a 12 m drawing pole with scale (Visalakshi 1995).

Soils were sampled and described by digging one or two soil profiles, each over 30 cm deep, in every sampling plot (Nirmal Kumar et al. 2010a). Soil samples were taken from different soil horizons in every profile. Prior to analysis, samples were air dried, ground, and then passed through a 2-mm sieve. Soil pH was measured in a 1:2 mixture of soil and deionized water using a glass electrode. Organic carbon determined by Walkley and Black method (Walkley & Black 1934); total N determined by micro-Kjeldahl technique (APHA 1998); available phosphorus was estimated by phosphomolybdic blue colorimetric method; potassium (K) and sodium by flame photometry. Calcium (Ca) and magnesium (Mg) were determined by EDTA titration method (Maiti 2003).

Data analysis

A combination of density, frequency and basal area is often used to measure the relative importance of a woody species in a forest community (Whittaker 1975). The plant frequency index depends greatly on sampling plot size (Crawley 1986) and is a useful index whenever the sampling covers a substantially large area. As our sampling plot size was relatively small, we used a combination of the relative basal area (RBA) and relative density (RD) of each woody species per sampling plot as the importance value (IV) (Basnet 1992):

IV (%) = (RBA + RD) / 2

where: *RD* (percent) was calculated by summing the number of stems of a species in a plot, dividing by the total number of stems of all species in the plot, and multiplying by 100. *RBA* (percent) was calculated in the same way using the basal area instead of the number of stems. Three parameters of the plant community, species richness (*S′*), diversity index (*H′*) and equitability index (*J′*) were calculated for each sampling plot. *S′, H′* and *J′* were calculated according to known equations (Pielou 1975):

$$S' = \log_2 S$$

$$H' = -\Sigma (P_i \cdot \log_2 P_1)$$

$$J' = H' / S'$$

where: *S* the total number of species occurred in each sampling plot and P_i the importance value of the *i* th species. To explore for any relationships between structure parameters and soil chemical properties, we used Pearson correlation analysis on the statistical package Kyplot (http://www.kyenslab.com/en/products/kyplot.html). As recommended by TerBraak (1995), all structural parameter values were log-transformed (ln) to meet the assumption of normality before entering the analysis, as their distributions were skewed towards a few very large values. The accepted level of significance was $p < 0.05$. The nomenclature of species in the present paper follows Shah (1978).

Results

Structural characteristics

Dry deciduous forest in Rajasthan was relatively low in stature. Mean canopy height was about 10 m, and 90% of the sample plots had canopy height less than 12 m (Fig. 2B). *Tectona grandis* L. reached a height of 15 m; *Anogeissus latifolia* (Roxb. ex DC.) Well. exGuill. & Perr. and *Boswellia serrata* Roxb.exColeb., reached 12-13 m in height. Stem density (≥ 3.0 cm DBH) averaged 995 stems.ha^{-1} (Fig. 2C); and about 48% of those stems were larger than 10 cm DBH. The mean DBH was 14 cm. The largest stems (> 40 cm DBH) were exclusively *T. gradis* (maximum DBH 79.0 cm), *B. monosperma* (68.1 cm), *Boswellia serrata* (67.2 cm), *Wrightia tinctoria* (61.3 cm), *Tamarix indica* (56.0 cm), *Miliusatomentosa* (54.5 cm), and *Madhuca indica* (47.3 cm) (Table 1). The mean total basal area of stems was 46.36 m^2·ha^{-1}. Approximately 65.5 % of the basal area occurred in stems with DBH ≥ 10 cm (Fig. 2D). *T. grandis*, however, accounted for 44.9% of the total basal area.

Floristic composition and tree species diversity

A total of 50 tree species (≥ 3.0 cm DBH) of 29 families was identified in 25 plots. The mean number of species per plot was 34 (Fig. 2A). The families that had the most number of species were *Mimosideae* (5 species), *Combretaceae* (5), *Fabaceae* (4), *Verbenaceae* (2) and *Rubiaceae* (2). 16 families (55.2% of the total) had only one species in all sampled plots (Table 2). Among total of 50 species, *T. grandis, B. monosperma, A. squamosa, B. serrata, W. tinctoria M. tomentosa, D. melanoxylon, M. indica* and *Bombax ceiba* were encountered in all sampled plots (Table 1). *T. grandis* had the highest importance value (20.81%) almost two times that of *B. monosperma* which had the second highest importance value (9.0%). *T. grandis* ranks as the dominant species of this dry tropical forest of Rajasthan, Western India. Tree species richness (DBH ≥ 3.0 cm) was 27 per plot; the species richness index averaged 5.57 and ranging from 3.07 to10.18 the diversity index (mean of 1.08) varied from 0.85 to 1.29 and equitability index (mean value 0.71)

Table 1 Importance tree species with importance value (*IV*) in dry tropical forest of Rajasthan, western India. Quantitative parameters: *N* - number of individuals, *PN* - number of plots, *BA* - total of basal area (m^2); D_{max} - maximum diameter at the breast height (cm), H_{max} - maximum height (m), *IV* - importance value (%). Species are ranked by descending *IVs*

Name of the species	*N*	*PN*	*BA*	D_{max}	H_{max}	*IV*
Tectona grandis L.f.	1533	25	4.97	79.0	15	20.81
Butea monosperma (Lam.) Taub.	829	25	3.69	68.1	8	9.00
Annona squamosa L.	300	25	0.31	19.8	10	3.08
Boswellia serrata Roxb. ex Coleb.	207	25	3.60	67.2	13	2.72
Wrighti atinctoria (Roxb.) R. Br.	184	25	2.99	61.3	7	2.38
Miliusa tomentosa (Roxb.) Sinclair	147	25	2.37	54.5	6	1.90
Diospyros melanoxylon Roxb.	132	25	1.02	35.7	8	1.51
Madhuca indica J.f. Gmelin.	114	25	1.78	47.3	4	1.46
*Lannea coromandeliaca (*Houtt.) Merr.	105	20	0.93	34.2	8	1.22
Bombax ceiba L.	83	25	0.83	32.3	9	0.98
Azadira chtaindica A. Juss.	76	21	0.67	29.1	7	0.88
Acacia nilotica (L.) Del. ssp. *Indica* (Benth.) Brenan	80	20	0.36	21.3	11	0.87
*Albizia lebbeck (*L.) Benth.	67	25	0.62	27.9	8	0.78
Acacia leucophloea (Roxb.) Willd.	72	20	0.28	18.7	12	0.77
Tamarix indica Willd.	28	18	2.50	56.0	5	0.72
Adina cordifolia (Roxb.) Bth. & Hk.	64	19	0.31	19.7	9	0.70
Ailanthus exelsa Roxb.	45	19	1.11	37.4	12	0.65
Dalbergia sissoo Roxb.	48	20	0.66	28.7	6	0.60
Aegle marmelos (L.) Corr.	55	19	0.21	16.2	9	0.59
Termina liabellerica (Gaertn.) Roxb.	42	16	0.84	32.4	8	0.57
Ficus benghalensis L.	24	16	1.76	47.0	7	0.55
Ponga miapinnata (L.) Pierre	43	15	0.62	27.9	9	0.54
Cassia fistula L.	45	20	0.44	23.4	8	0.53
Cordia dichotoma Forst. f.	31	17	1.02	35.7	7	0.49
Wrightia tomentosa R. & S.	31	16	0.95	34.5	8	0.48
Acacia senegal (L.) Willd.	43	19	0.22	16.7	8	0.47
Cordiagharaf (Forsk.) Ehrenb. & Asch.	35	15	0.55	26.3	12	0.45
Terminalia crenulata Roth	31	12	0.73	30.2	9	0.44
*Anogeissus latifolia (*Roxb. ex DC.) Well.	33	16	0.58	27.0	14	0.43
Syzygium cuminii (L.) Skeels	29	14	0.58	26.9	6	0.39
Bridelia retusa Juss.	31	13	0.44	23.5	8	0.39
Ficus religiosa L.	12	9	1.47	43.0	8	0.38
Limonia acidisima L.	30	13	0.44	23.4	8	0.38
Holoptelea integrifolia (Roxb.) Planch.	28	14	0.47	24.2	6	0.36
Gmelina arborea Roxb.	28	13	0.43	23.1	7	0.36
Moringa concanensis Nimmo ex Dalz. & Gibs.	30	16	0.28	18.7	9	0.35
Zizyphus nummularia (Burm.f.) W. & A.	30	18	0.20	15.8	7	0.34
Anogeis suspendula Edgew.	27	17	0.29	19.0	5	0.32
Terminalia arjuna (Roxb. ex DC.) Wt. & Arn.	21	11	0.59	27.3	8	0.32
Tecomella undulata (Seem) Seem	22	10	0.48	24.5	6	0.31
Morinda tomentosa Heyne ex Roth	20	12	0.45	23.7	11	0.28
Sterculi aurens Roxb.	15	10	0.62	27.9	8	0.26
Mangiferaindica L.	17	12	0.44	23.4	9	0.25
Phoenix sylvestris (L.) Roxb.	21	13	0.16	14.3	9	0.24
Sapindus laurifolius Vahl.	15	11	0.49	24.8	8	0.24
Bauhinia variegata L.	18	12	0.31	19.7	9	0.24
Pterocarpus marsupium Roxb.	10	8	0.49	24.9	7	0.19
Phyllanthus emblica L.	11	8	0.36	21.4	9	0.17
Capparis decidua (Forssk.) Edgew.	14	11	0.13	12.8	10	0.16
Prosopis cineraria (L.) Druce	6	5	0.33	20.3	5	0.12

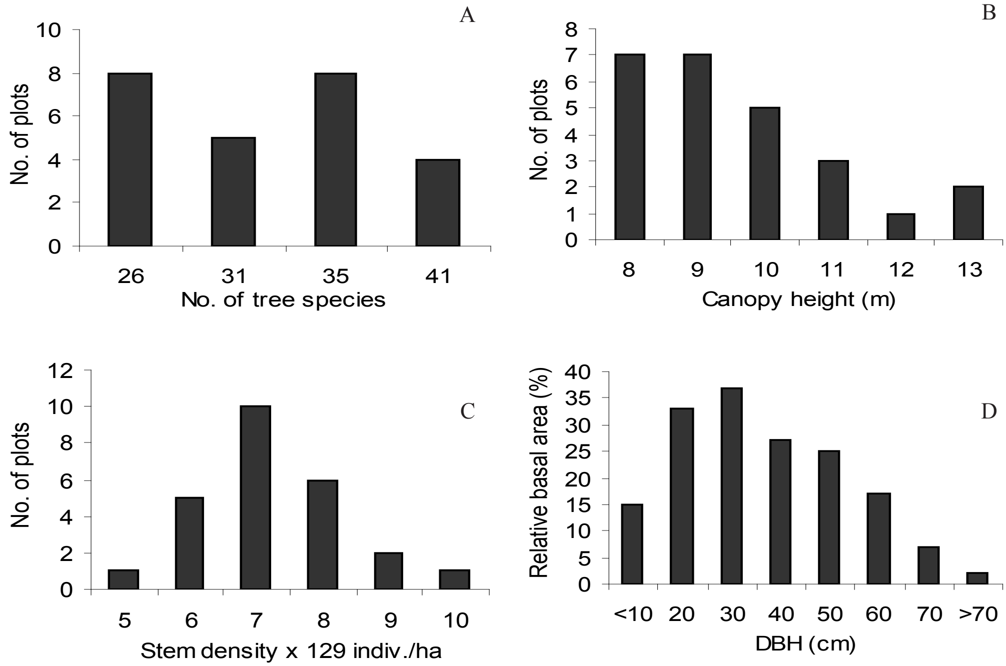

Figure 2 Distribution of sampling plots number by: (A) number of tree species, (B) mean canopy height, (C) stem density and (D) distribution of basal area

from 0.58 to 0.81. The relationships between dominant species and diversity indices were examined by simple linear regression. The result showed that species diversity indices appeared obviously declined with the increase in importance value of the dominant (R = -0.738 for H′; R = -0.759 for *J′* and R = -0.760 for *S′*). Species richness was significantly and negatively related to the relative density of *T. grandis*, but not related to the relative basal area of this dominant.

Soil chemical properties

The soils of the study site had a thin A horizon, usually less than 10 cm thick, and an average pH of 6.16, ranging from 5.65 to 6.67. Soil nutrients are summarized in Table 3. The dominant exchangeable cations were Ca^{2+} and Mg^{2+}. The analysed cations differed in their vertical concentration gradients: Na^{+} changed little down the profile, but K^{+} and Mg^{2+} were markedly concentrated toward the top. Exchangeable K^{+} and Ca^{2+} in the surface soil horizons were the most variable properties with a coefficient of variation of 97.2% and 78.2%, respectively. Furthermore, more than half of the stands sampled had exchangeable K^{+} values lower than 0.20 cmol (+) kg^{-1}. However, soil total N and available P concentrations were somewhat high, especially for A horizons. Most of the soils sampled had rather high values for organic C (mean value, 6.78%) in the top horizons.

Analysis of Pearson correlation coefficients (Table 4) indicates that there is no significant relationship between basal area and any individual soil chemical properties. However, there is a negatively significant relationship between stand density and soil pH (p = 0.009). The dominant tree height is positively correlated to soil pH ($p < 0.001$), and is negatively correlated to C:N and C:P ($p < 0.001$). The species diversity index has positively significant correlations with available P, exchangeable K^{+} and Ca^{2+} and has negative correlations with

Table 2 Family importance values for the 29 ecologically most important families

Family	Number of stems	BA	Number of Species	FIV (%)
Verbenaceae	1561	4.97	2	40.10
Fabaceae	930	1.11	4	20.63
Burseraceae	207	3.60	1	10.51
Annonaceae	447	0.30	2	9.50
Apocynaceae	215	1.83	2	7.54
Mimosideae	268	0.37	5	6.03
Sapotaceae	114	1.78	1	5.44
Tamaricacae	28	2.43	1	4.87
Ebenaceae	132	1.01	1	4.44
Combretaceae	154	0.59	5	4.13
Moraceae	36	1.71	2	3.74
Anacardiaceae	122	0.66	2	3.61
Meliaceae	98	0.67	1	3.16
Bombacaceae	83	0.83	1	3.13
Simaroubaceae	45	1.11	1	2.86
Ehretiaceae	66	0.62	2	2.41
Rubiaceae	84	0.32	2	2.25
Rutaceae	85	0.21	2	2.08
Caesalpinioideae	63	0.41	2	1.98
Myrtaceae	29	0.58	1	1.60
Euphorbiaceae	42	0.37	2	1.51
Sterculiaceae	15	0.62	1	1.40
Ulmaceae	28	0.45	1	1.36
Bignoniaceae	22	0.48	1	1.29
Sapindaceae	15	0.49	1	1.17
Moringaceae	30	0.28	1	1.09
Rhamnaceae	30	0.20	1	0.95
Arecaceae	21	0.16	1	0.71
Capparaceae	14	0.13	1	0.51

organic C, total N, C:N and C:P ratio. Therefore, compositional and structural differences within the dry tropical forest were significantly correlated to the spatial variation of soil properties, indicating that soil properties may have a substantial influence on the composition is subtropical forest.

Discussion

Forest structure. Importance values indicate that Rajasthan dry tropical forest is dominated by relatively few species. *T. grandis* is the dominant species, which comprises 21.81% of the total importance value. This value is similar to the dominant species in tropical semi-evergreen forest of Kalayan hills, Eastern Ghats, India (Kadavul & Parthasarathy 1999), and is high in comparison to the subtropical evergreen forests in Taiwan (Hara et al. 1997) and tropical rainforests in Amazon (Mori et al. 1983, Milliken 1998). Another structural characteristic of the Rajasthan dry tropical forest is relatively low over-story canopy. The mean stem density for trees over 3.0 cm DBH was

Table 3 Soil chemical properties for dry tropical forest of Rajasthan, Western India

Depth (cm)		pH (H_2O)	Org-C (%)	TN (%)	Avail P (mg kg^{-1})	Exchangeable bases (cmol (+) kg^{-1}			
						K^+	Ca^{+2}	Mg^{+2}	Na^+
A 0-10	Mean	5.65	6.78	0.18	68.45	0.35	2.83	1.52	0.63
	S.D.	0.08	0.05	0.03	1.03	0.03	0.07	0.04	0.05
B1 10-20	Mean	6.15	3.53	0.23	28.34	0.19	1.29	0.73	0.38
	S.D.	0.03	0.06	0.02	2.00	0.02	0.05	0.05	0.05
B2 20-30	Mean	6.67	2.17	0.28	14.14	0.09	0.79	0.53	0.44
	S.D.	0.09	0.04	0.04	1.50	0.02	0.04	0.05	0.03

Table 4 Pearson correlation coefficients between diversity indices, logarithmically transformed structure parameters and soil chemical properties (N = 25). Significant levels: * p < 0.05, **p < 0.01, ***p < 0.0001

	pH	Org-C	TN	Avail-P	K	Ca	Mg	Na	C:N	C:P
H’	0.036	-0.055*	-0.020*	0.183*	0.443***	0.560***	-0.083	0.034	-0.101**	-0.015***
J’	0.064	-0.003	-0.027	0.123**	0.557**	0.479***	-0.076	0.188	-0.074**	-0.040***
s’	0.134	-0.058*	-0.117	0.219**	0.447**	0.583**	-0.027	0.233	-0.151**	-0.053**
BA	0.099	-0.348	-0.169	0.301	0.307	0.254	-0.349	0.240	0.356	-0.223
Density	0.509*	0.917	0.615	0.341	-0.810	0.290	0.489	0.513	0.345	0.377
D_{mean}	0.024	-0.330	-0.117	0.322	0.313	0.281	-0.385	0.280	0.316	-0.270
H_{mean}	-0.408	0.033	0.329	0.394	-0.061	0.379	0.234	0.034	0.228	-0.240
H_D	0.704***	-0.269	0.066	0.259	0.307	0.189	-0.253	-0.036	-0.212**	-0.324*

995 stems·ha^{-1}, and the stems less than 10 cm DBH contributed 52%. Those values are rather higher than the other dry tropical forests (Nirmal Kumar et al. 2010b, Nirmal Kumar et al. 2001). Furthermore, the Rajasthan dry tropical forest has a canopy height usually lower than 15 m. Such a great density and a low canopy in our site may be attributed to persistent strong monsoon winds (Telewski 1995), and/or to soil properties, such as light acidity and shortage of P and K (Grubb 1977).

Tree species diversity. The 50 tree species, from 29 families, recorded in this study reflect the high tree species diversity of Rajasthan dry tropical forests. One recent study by Kadavul and Parthasarathy (1999) recorded 89 tree species of (over 3.0 cm DBH) within a 1-ha square plot. Another study by Chowdhury et al. (2000) recorded a higher diversity of more than 85 tree species (> 3.0 cm DBH) in a 20 m × 20 m plot.

Structure and species diversity in relation to soil properties. Nutrient levels in dry tropical forest are indicative of a soil with relatively low fertility. Exchangeable K^+ and Mg^{2+} mean values of 0.35 and 1.52 cmol (+) kg^{-1} respectively for the surface mineral soil horizons are within the ranges in nutrients found in dry tropical forest soils in northeast India (Supriya & Yadav 2006). Mean concentrations of exchangeable Ca^{2+} and available P in Rajasthan are low compared to levels in north east India. Comparably low levels of nutrients to our site have been reported by Stark (1971) for Amazonian rainforests and by Proctor et al. (1983) in Southeast Asia. On the other hand, levels of organic carbon seem rather high in the top soils (the mean value reached 6.78% ranging from 2.13% to 6.83%).

It is revealed that the dry tropical forest of

Rajasthan is species-rich, with high-density and small-statured forest structure, where few large emergents and many small-stemmed individuals are present. Such a structural character may be controlled by soil chemical properties, particularly soil pH.

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