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Vegetation patterns depend on the underneath soil nutrient factors: A report from a dry deciduous forest of West Bengal, India

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Abstract
The study investigated different soil nutrient factors under different vegetational covers of a dry deciduous forest of West Bengal named Ballavpur Wildlife Sanctuary which is a created and protected forest. Simultaneous with the vegetation study 75 soil samples were collected from 25 quadrats of the studied forest and tested for different physico-chemical parameters. Vegetation- environment interactions were studied by Canonical Correspondence Analysis (CCA). The result showed that vegetation is not affected by any soil parameter in isolation, but a complex of interrelated parameters makes an impact. Many soil parameters displayed significant correlations among themselves. Available soil nutrients like sodium, potassium, phosphorus, available nitrogen contents etc were some common determining factors for controlling species distribution. *Pterocarpus marsupium*, *Shorea robusta* and *Madhuca longifolia* var *latifolia* showed preference of higher values of available soil nutrients in our studied forest.

Keywords: forest ecosystem, species distribution, soil nutrients, vegetation-environment interaction

Introduction
The tropical deciduous forest supports a nutrient deficient soil. Distribution of plants in the forest is a function of a set of critical and measurable environmental variables. Soil abiotic and biotic structure and function are keys in nutrient cycle dynamics and plant community composition (Eaton *et al*., 2011) [1]. Several studies documented the prominent role of environmental factors, particularly soil physico-chemical factors in determining diversity and distribution of plants in tropical forests (Laurence *et al*., 2010; Toledo *et al*., 2012; Sarker *et al*., 2014) [2, 3, 4]. In tropical forest ecosystems, soil nutrients play an important role in formation of plant communities, their species composition and structural diversity. Diversity change may be related to initial nutrient condition of the community and nutrient enrichment increase biodiversity in poor soils (Theresa and Bowman, 1997; Kumar *et al*., 2010) [5, 6].
The heterogeneous distribution of soil nutrients plays an important role in erosion of soil factors, as well as the uptake and sequestration of the nutrients in accumulated litter and soil organic matter under different canopies. Quantification of ecological relationship between vegetation and environment has become one of the major issues in the modern community ecology following the advent of multivariate statistical techniques (Legendre and Legendre, 1998) [7]. Canonical Correspondence Analysis (CCA) is one of the popular ordination methods.
The study area in present work falls under tropical part of West Bengal and is characteristically dry deciduous in nature on red lateritic soil. A previous work thoroughly explained the vegetation structure and species distribution of the studied forest (Ganguli *et al* 2016b) [8]. In present study we investigated the vegetation- environment interactions under the same vegetational cover with the help of multivariate statistical analysis. This study was performed to identify the underlying factors, which affect the vegetation cover of a particular ecosystem. To our knowledge this is the first study to focus on the correlation of vegetation parameters with soil parameters of this particular dry deciduous forest.

Materials and methods
Area description
A dry deciduous protected forest of West Bengal, Ballavpur wild life sanctuary was selected as our study area. The forest is situated in the Birbhum district and extends between 23°39'25"N latitude to 87°41'39"E longitude and typically falls under biogeographic zone 7B-Choto Nagpur plateau (Figure 1). The forest is manmade and the creation was done in phased manner between the years 1953 to 1999 and included within the jurisdiction of Bolpur Range under the Birbhum Forest Division of South East circle. This forest includes 3 wetland sites inside, where large numbers of migratory birds come in winter season and is a protected forest. The altitude ranges from 50 to 64 meters above the sea level.
The climate of the study areas is tropical and temperature ranges from 34˚C to 45˚C in the summer and 8˚C to 15˚C in the winter. Annual rainfall ranges from 120 to 150 cm. Soil is red lateritic which is known for high level of iron content and poor in nutrient status.
Ballavpur wildlife sanctuary is dominated by *Acacia auriculiformis* (Linn. A. Cunn) belonging to Mimosaceae family.

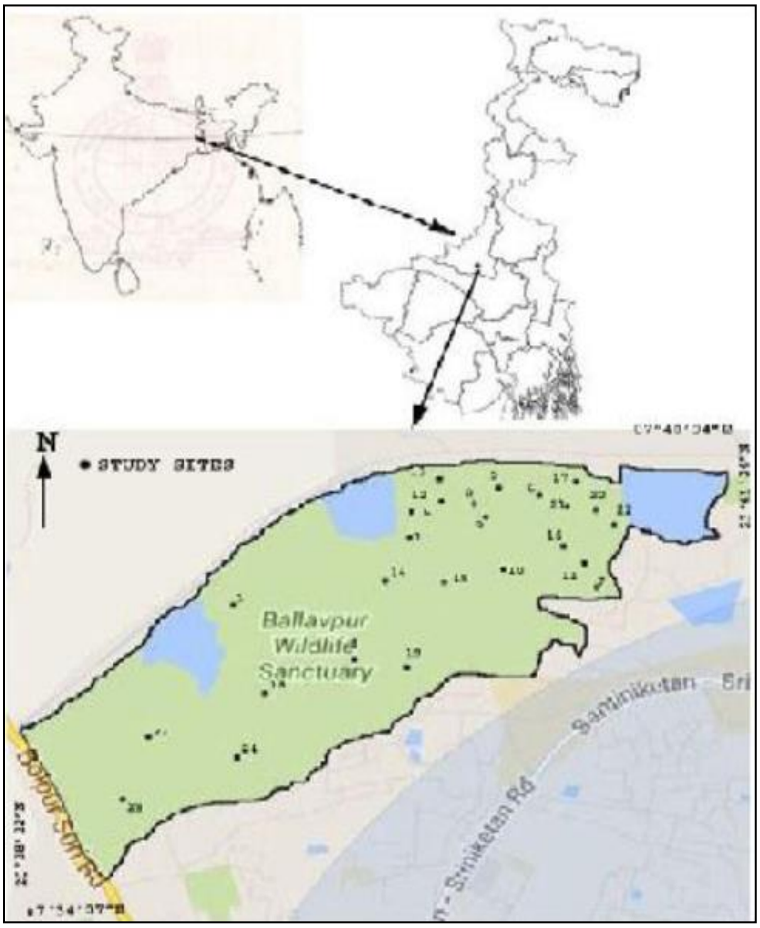

Fig 1: Map showing study sites.

Vegetation sampling

The vegetation was sampled randomly by laying 25 quadrats of 10m x 10m each, covering 0.25 ha area in the study site. In each quadrat all the trees (dbh>1cm) were identified and their number and diameter at breast height (dbh) were recorded with the help of a slide caliper. Where dbh measurement was not possible, girth at breast height (gbh) was measured using a meter tape. The shrubs, climbers and tree saplings (< 1cm dbh, height >30 cm) were sampled in two 5m x 5m quadrats, and herbs including tree seedlings (< 1cm dbh, height <30 cm) were sampled by lying four 1m x 1m quadrats nested within each 10m x 10m quadrat. Plant specimens were collected and identification of the unknown species was done by consulting regional flora (Sanyal, 1994; Guha Bakshi, 1990) [9, 10].

Phytosociological characters like frequency, density, basal area and importance value index (IVI) were calculated for each tree species according to Misra (1968) [11].

Soil sampling

Simultaneous with the vegetation study three soil samples were collected from 10cm depth in each of the twenty five quadrats of the studied forest summing up to 75 samples. Soil samples were brought to the laboratory, sieved through a 2 mm mesh screen and tested for different physico-chemical parameters.

Soil Analysis

Different physical parameters like pH, conductivity, soil moisture, soil texture, water holding capacity (WHC), bulk density, and chemical parameters like available Nitrogen (N), Sodium (Na), Potassium (K), Phosphorus (P), organic Carbon (C) were measured. Soil texture was analyzed by Hydrometer method (Bouyoucos 1927) [12]. Soil pH and conductivity were determined by using pH meter (1:2 soil: water ratio) and conductivity meter (1:5 soil: water ratio) respectively. Gravimetric soil moisture was determined by drying the soil samples at 105˚ C for 24 hours in a hot air oven (Buresh 1991) [13]. Water holding capacity (WHC) and bulk density were measured by Keen's box method.

Mineral N (NH_4^+-N and NO_3^--N) was estimated using Kjeldahl distillation method (Jackson 1958) [14]. Available – P was determined by Olsen's extraction method (1954) [15]. Available– Na and K was determined by flame photometric method (Jackson 1958) [14]. Organic carbon was determined by Walkley and Black's method (Walkley 1947) [16] and organic nitrogen according to Jackson (1958) [14].

Statistical Analysis

To understand the effect soil factors on the vegetation, Canonical Correspondence Analysis (CCA) was used, which tested the relationship between plant community composition and measured edaphic variables in XLSTAT 2016 [17].

Results

Vegetation structure

In Ballavpur wildlife sanctuary a total of 1212 woody individuals (≥1cm dbh) of 21 species (19 genera) from 12 families were recorded in a previous study from the random quadrats covering 0.25 ha (Table 2) (Ganguli *et al* 2016b) [8].

According to Ganguli *et al.* 2016b [8] the family Mimosaceae had the greatest number of individuals (373) of single species and the family Meliaceae and family Casuarinaceae were represented by single species having single individual each. Among the 25 studied quadrats the number of species ranged from 1 to 9 and individuals from 13 to 110 per quadrat (Table 1). The number of individuals of various species varied from 1 to 373. Total mean stem density in the area studied was 4848 N ha-1. However, the total density of stems with dbh ≥ 10 cm was 560ha-1. Quadrat wise the stem density varied from 4 to 1492ha-1 with a mean of 48.48 stems.

Table 1: Quadrat wise species distribution in Ballavpur wildlife sanctuary.

	Quadrat No.(1-25)																									
Species names (Families)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Total no
Acacia auriculiformis Benth. (Mimosaceae)	14	16	29	11	11	22	32	4	5		2	16	21	1		4	11	6	10	39	29		47	42	1	373
Shorea robusta Gaertn. f. (Dipterocarpaceae)				53		11		5	63	1	21			25	26		43	48	1		8	17		8	5	335
Syzygium cumini (L.) Skeels (Myrtaceae)	39	6		15	19	14	19	2	18		3	5	3	5	14	6		6		11	8					193
Terminalia bellirica (Gaertn.) Roxb. (Combretaceae)	7		4	1	7	6			2			6	8		1	9	1				11					63
Pterocarpus marsupium Roxb. (Fabaceae)			1		2	3				2	2					4			6		1	1				22
Madhuca longifolia var. *latifolia* (Roxb.) A. Chev. (Sapotaceae)									4	1	2	2												2	8	19
Buchanania lanzan Spreng. (Anacardiaceae)	1	1		2	1	2			8		4		1	6		1										27
Cassia siamea Lam. (Caesalpiniaceae)										42								1	1							44
Madhuca longifolia (J.Koenig ex L.) J.F.Macbr. (Sapotaceae)		12		1										4	3			10								30
Terminalia arjuna (Roxb. Ex DC.) Wight & Arn. (Combretaceae)																				38						38
Anacardium occidentale L. (Anacardiaceae)						3		2			2			3		3										13
Xylia xylocarpa (Roxb.) Taub. (Euphorbiaceae)				27																						27
Phyllanthus emblica L. (Euphorbiaceae)		4														3										7
Millettia pinnata (L.) Panigrahi (Fabaceae)						1								1												2
Eucalyptus tereticornis Sm. (Myrtaceae)																								2	1	3
Butea monosperma (Lamk.) Taub. (Fabaceae)															9											9
Suregada multiflora (A. Juss.) Baill. (Euphorbiaceae)						2				1																3
Casuarina equisetifolia L. (Casuarinaceae)														1												1
Alstonia scholaris (L.) R. Br. (Apocynaceae)										1																1
Thevetia peruviana (Pers.) K. Schum. (Apocynaceae)										1																1
Azadirachta indica A. Juss. (Meliaceae)	1																									1

Table 2: Phytosociological characteristics of tree species in Ballavpur wildlife sanctuary (Ganguli *et al* 2016b) [8].

Species (Family)	Total individuals	Density (N ha^{-1}) ± SD	Frequency (%)	Basal area (m^2 ha^{-1})	IVI
Acacia auriculiformis Benth. (Mimosaceae)	373	1492 ± 1392.3	88	5.74	75
Shorea robusta Gaertn. f. (Dipterocarpaceae)	335	1340 ± 2032.1	60	6.61	70
Syzygium cumini (L.) Skeels (Myrtaceae)	193	772 ± 921.2	68	0.86	34
Terminalia bellirica (Gaertn.) Roxb. (Combretaceae)	63	252 ± 341.4	48	2.18	25
Pterocarpus marsupium Roxb. (Fabaceae)	22	88 ± 166.6	36	2.11	19
Madhuca longifolia var. *latifolia* (Roxb.) A. Chev. (Sapotaceae)	19	76 ± 256.2	24	1.69	14
Buchanania lanzan Spreng. (Anacardiaceae)	27	108 ± 249.6	40	0.21	12
Cassia siamea Lam. (Caesalpiniaceae)	44	176 ± 2367.1	12	0.66	9.1
Madhuca longifolia (J.Koenig ex L.) J.F.Macbr. (Sapotaceae)	30	120 ± 474.3	20	0.14	7.3
Terminalia arjuna (Roxb. Ex DC.) Wight & Arn. (Combretaceae)	38	152	4	0.67	6.9
Anacardium occidentale L. (Anacardiaceae)	13	52 ± 54.7	20	0.08	5.6
Xylia xylocarpa (Roxb.) Taub. (Euphorbiaceae)	27	108	4	0.45	5.1
Phyllanthus emblica L. (Euphorbiaceae)	7	28 ± 70.7	8	0.45	4.3
Millettia pinnata (L.) Panigrahi (Fabaceae)	2	8	8	0.29	3.2

Eucalyptus tereticornis Sm. (Myrtaceae)	3	12 ± 70.7	8	0.09	2.3
Butea monosperma (Lamk.) Taub. (Fabaceae)	9	36	4	0.09	2
Suregada multiflora (A. Juss.) Baill. (Euphorbiaceae)	3	12 ± 70.7	8	0.002	1.9
Casuarina equisetifolia L. (Casuarinaceae)	1	4	4	0.16	1.6
Alstonia scholaris (L.) R. Br. (Apocynaceae)	1	4	4	0.02	1
Thevetia peruviana (Pers.) K. Schum. (Apocynaceae)	1	4	4	0.01	1
Azadirachta indica A. Juss. (Meliaceae)	1	4	4	0.0007	0.9
21 species	1212	4848		22.49	300

Physico-chemical properties of soil

The Physico-chemical properties of soil in the study site are presented in Table 3. Soil pH was in acidic range. The study site was nutritionally poor and available phosphorus (P), available potassium (K), and available sodium (Na) were present in very low range.

Table 3: Physico-chemical properties of soil in the study site

Soil parameters	Range	Mean
Avail N (ppm)	20.40 to 95.20	41.96 ± 19.78
Avail P (ppm)	0.02 to 0.04	0.03 ± 0.003
Avail Na (ppm)	8.67 to 26	13.76 ± 4.59
Avail K (ppm)	5.33 to 27.67	11.03 ± 5.19
pH	3.50 to 6.02	5.18 ± 0.62
EC (µs/ cm)	19.80 to 62.10	30.32 ± 10.74
WHC (%)	19.27 to 39.99	28.04 ± 4.80
Org C (%)	0.11 to 1.70	0.62 ± 0.40
Moisture (%)	0.90 to 45.40	7.69 ± 8.45
Sand (%)	61.34 to 68.45	66.31 ± 1.87
Silt (%)	0.04 to 2.10	0.83 ± 0.59
Clay (%)	30.35 to 37.66	32.86 ± 2.0
Bulk D (gm cm^{-3})	1.29 to 1.86	1.65 ± 0.15

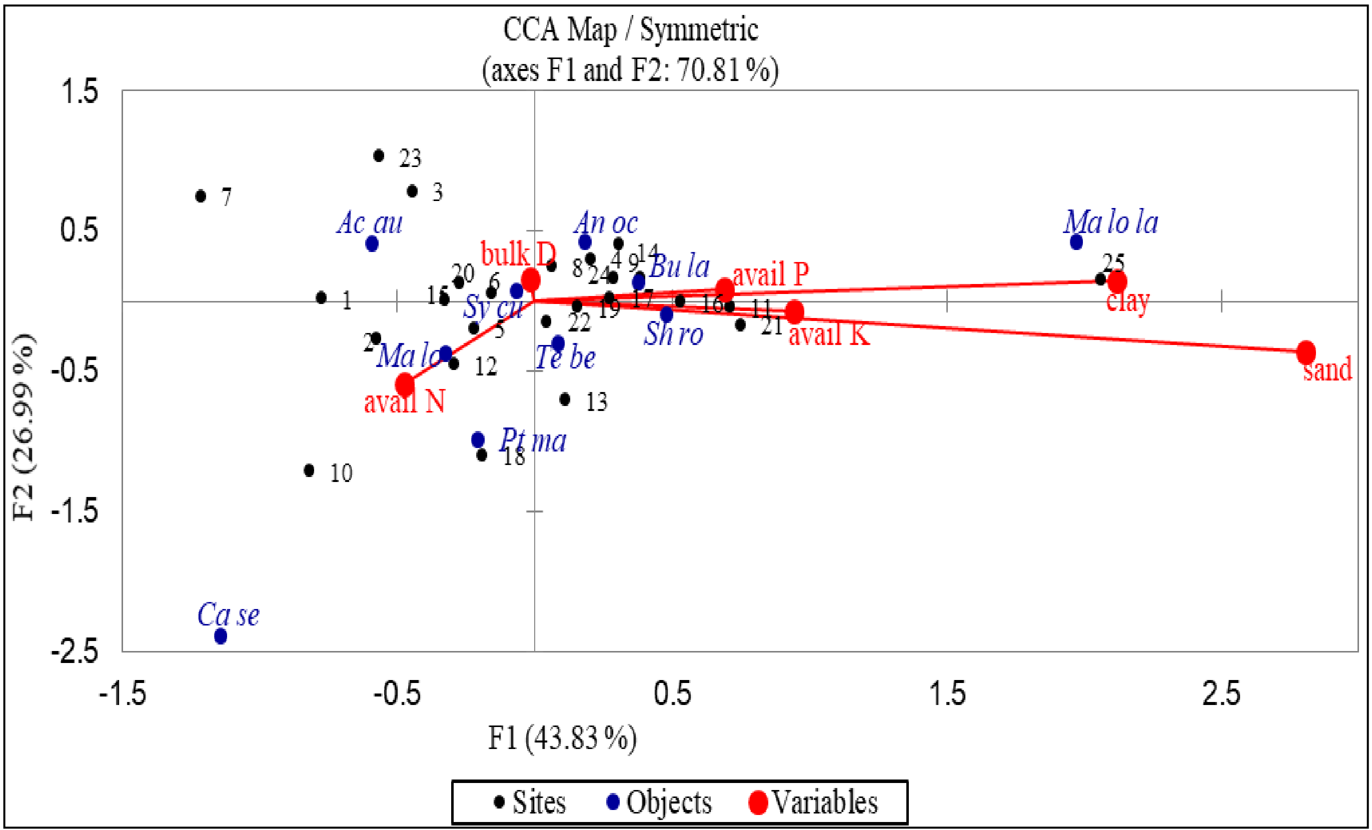

Fig 2: Canonical Correspondence Analysis.

In our study area sand, clay, available K and available P were important along CCA axis1. Available N was related to CCA axis2 as indicated by length of these vectors. Range of variation in bulk-density was low (Figure 2). *Maduca longifolia* var *latifolia* prefer high clay and available P. *Cassia seamia*, *Pterocarpus* marsupium and *Madhuca longifolia* prefer more available N. Shorea robusta prefer high sand and available K while *Acacia auriculiformis* prefers low sand and available K. *Anacardium occidentale* prefers low available N.

Table 4: Correlations between soil parameters of Ballavpur WLS (n=25). (a=p<0.05; b=p<0.01; c=p<0.001)

Variables	sand	avail N	avail P	avail K	clay	bulk D	EC	avail Na	pH	WHC	org C	moisture	silt
sand	1												
avail N	0.151	1											
avail P	-0.785[c]	-0.296	1										
avail K	0.157	0.175	-0.212	1									
clay	-0.956[c]	-0.120	0.653[c]	-0.219	1								
bulk D	-0.010	-0.711[c]	0.238	-0.403[a]	0.033	1							
EC	-0.458[a]	-0.117	0.460[a]	-0.257	0.438[a]	0.010	1						
avail Na	-0.254	-0.180	0.304	-0.221	0.248	0.168	0.373	1					
pH	-0.247	-0.028	0.125	-0.386	0.300	0.010	0.106	-0.102	1				
WHC	0.169	0.451[a]	-0.416[a]	0.414[a]	-0.135	-0.597[b]	-0.295	0.025	0.066	1			
org C	0.017	0.312	0.054	0.313	-0.034	-0.138	-0.043	0.130	0.114	0.359	1		
moisture	0.057	0.075	-0.129	0.029	-0.112	-0.312	-0.123	-0.178	-0.106	0.195	-0.035	1	
silt	0.065	-0.075	0.283	0.247	-0.353	-0.081	-0.031	-0.034	-0.234	-0.081	0.063	0.201	1

Discussion

The result indicated a nutritionally poor acidic soil in the studied forest where the dominant soil particle was sand. Lateritic soils of this region are characterised by acidic pH (4.8 to 5.5), low NPK content and high iron as reported by many studies (Raychaudhuri, 1980; Choudhury, 1973; Ojha and Chattopadhyay, 1976; Chakraborty *et. al*., 2002) [18, 19, 20, 21]. Soil pH significantly affects plant growth primarily due to the change in availability of both essential elements such as phosphorus (P), as well as non-essential elements such as aluminium (Al), that can be toxic to plants at elevated concentrations (Slattery *et al*., 1999) [22]. The primary nutrients, e.g., nitrogen, phosphorus and potassium, as well as the secondary nutrients, e.g., calcium and magnesium, are available or more available at a pH of 5.5 for organic and 6.5 for mineral soils, than at any other pH (Donahue *et al*., 1985) [23]. In the present study, the mean soil pH was below 6 (Table 3). The leaching processes responsible for the removal of silica in the formation of lateritic soils also remove a large portion of the bases originally present in the rock and soil, thus having a residue rich in iron and aluminium and poor in potash and phosphoric acid; nitrogen deficiency is not so much as that of potash and phosphoric acid (Raychaudhuri, 1980) [18].

Available sodium content was higher than available K^+ in soils of Ballavpur WLS. According to Epstein (1972) [24] sodium ion cause nutrient deficiency by reducing the amounts of available K^+ and other cations like Mg^+ and Ca^+. Available phosphorus was very low in the studied forests (Table 3). Nitrogen and phosphorus are two important nutrients that limit the primary productivity of forest ecosystems. Soils in Teak and *Butea* dominated tropical dry deciduous forests of western India are reported to have 2.23 to 2.81% organic carbon and high values of nitrogen and phosphorus (Kumar *et al*., 2010) [6], as compared to only 0.11 to 1.7% organic carbon in the present study. Sagar *et al*. (2003) [25] also reported comparatively higher values of organic carbon (1.18 to 2.79%), total phosphorus (0.008 to 0.011%) and total nitrogen (0.10 to 0.15%) from the Vindhyan tropical dry forests.

Vegetation is not affected by any soil parameter in isolation, but as these parameters tend to be highly correlated so a complex of interrelated parameters make its impact on the plants life. In present investigation, many soil parameters displayed significant correlations among themselves. For example in our present study, water holding capacity of the forest soil was positively related with available value of nitrogen and potassium, and negatively related with phosphorus (Table 4). Available nitrogen and potassium were negatively correlated with bulk density, which was negatively related to water holding capacity also. Available phosphorus was also negatively related to sand but positively with EC and clay content; EC and clay were negatively correlated.

Environmental gradients were meaningful in explaining species distribution patterns as indicated by CCA ordination (Figure 2). The first two axes explained 68 to 70 % variation in species composition. Results of CCA analyses indicated that distribution pattern of species do not follow a single environmental gradient, but a number of gradients are important and explained a high amount of variance. For instance, the first and second CCA axis strongly correlated with sand, clay, available potassium and available nitrogen in Ballavpur.

Although the measured environmental variables explained a very good amount of the variance in species composition, an appreciable proportion remained unexplained. This could be due to the unmeasured environmental variables like isolation, microclimate and also biotic interactions. Disturbance can also influence community composition and structure in tropical dry forests as indicated in PCA ordination by Sagar and Singh (2003) [26] where they found strong correlation of PCA axis with disturbance gradient.

Nonetheless, environmental factors strongly structured the distribution of some highly abundant species. Sand, available potassium, phosphorus and nitrogen were the most important factors in Ballavpur – *Shorea robusta*, *Madhuca longifolia*, *Madhuca longifolia* var *latifolia*, *Pterocarpus marsupium* preferred higher values than *Acacia auriculiformis* which preferred low values, suggesting its ability to tolerate low soil nutrients. All this suggests that *Acacia auriculiformis* is adapted for relatively unfertile soil having low NPK status.

Many studies have emphasized the importance of soil properties, particularly organic matter and available N, P, K, in governing the distribution of species. Soil nutrients remarkably influence plant species distribution, growth and development in the tropics (Santiago *et al*., 2012) [27]. Soil organic matter, acidity, phosphorus and calcium strongly influenced plant distribution (Sarker *et al*., 2014) [4]. Soil organic matter helps in recycling cations, maintains phosphorus availability, sequester nitrogen and prevent soil erosion (Palm *et al*., 2007) [28]. In present study also available phosphorus was negatively correlated with water holding capacity and sand content of the soil (Table 4). Availability of soil phosphorus significantly influence several physiological processes like photosynthesis rate, stomatal conductance and root growth in tropical plants (Wright *et al*., 2011) [29]. Phosphorus is the soil nutrient that frequently limits tree growth and productivity in oxisols and ultisols (Cleveland *et al*., 2002) [30]. Oxisols and ultisols are the soil orders having laterization as the main pedogenic process.

Forest management strategy may cause huge impact on forest ecosystem properties including vegetation parameters, soil nutrient status, litter fall, decomposition and associated nutrient cycling. As our studied forest was a protected one, the in-situ litter decomposition was not disturbed by the litter collection or manmade fires. As a result organic carbon and soil moisture was not found in that low range in Ballavpur WLS. Frequent fires might cause change in the soil properties. It may change the species composition as well as may lead to dominance of fire tolerant species in the open forests.

Significant correlations of available phosphorus with clay and three other parameters were recorded, and soil bulk density exhibited reciprocal relationship with water holding capacity (Table 4).

Available nutrients – potassium and nitrogen content as well as sand and clay contents were common determining factors for controlling species distribution in the studied forest.

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