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Leptadenia pyrotechnica in Indian hot arid Thar Desert: connecting link's among its spatial patterns with soil and community factors

Manish Mathur*, Mahesh Kumar and C.B. Pandey
ICAR-Central Arid Zone Research Institute, Jodhpur-342003, India
*Corresponding author e-mail: eco5320@gmail.com
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Abstract
Present study identifies the environmental (edaphic and community) as well as intrinsic factors associated with spatial distribution patterns of an Indian hot arid species, *Leptadenia pyrotechnica*. Spatial distribution patterns of this species were evaluated at nine sites with the help of three different indices (Lloyd's, Smith and Wilson and Morisita) and quantified patterns were linked with soil (particle size, pH, electrical conductivity, organic carbon, potassium and phosphorus), and community (richness, Simpson index of dominance, Shannon and Weaver index, evenness and community maturity index) factors. Besides spatial patterns, canopy volume and density of this species were also quantified. Attributes were statistically treated with canonical correlation analysis (CCoA) and two steps partial least square (PLS) regression. Clumped type spatial pattern for this species was identified with mean density and log abundance, while random patterns was identified with the number of sample units and the number of individuals in each sample unit. Regression equations for density, canopy volume, clumped (Lloyd's and Smith, and Wilson index) and random (Morisita index) patterns were developed by using significant variable importance for the projection (VIPs) values. Ecological information emerged from the present study might facilitate us to effectively use this species under restoration and rehabilitation programs.

Keywords: Canonical correlation**.** Community dynamics, *Leptadenia pyrotechnica*, PLS, Soil factors, Spatial patterns

Introduction
The horizontal organization of plant communities can be effectively described by explaining their physical arrangement or distribution within the community which in turn can prove to be a utilitarian tool in relation to spatial patterns of a species (Mathur, 2016; Chaikaew *et al.,* 2020). Knowledge of cause and effect relationships of plant spatial distribution patterns shall pulpit us for better understanding of ecosystem functions, stability, recovery/ restoration actions. Under natural conditions the plant species may exhibit three types of spatial patterns viz., clumped, random and regular. The processes that govern such spatial patterns operate at multiple levels incorporate topography, soil quality, accessibility of water and nutrients, seed dispersal (Dehghani and Ali, 2019; Tang *et al.,* 2019), interaction among individuals (Kang *et al.,* 2014), plant-plant interactions (Valiente-Banuet *et al.,* 2006; Mathur 2014a; 2014b), environmental heterogeneity (Perry *et al,.* 2008; Rayburn and Monaco, 2011) and disturbance via grazing (Seifan and Kadmon, 2006; Rayburn and Monaco, 2011).

Leptadenia pyrotechnica (Forssk.) Decne member of Asclepiadaceae an erect much branched leafless shrub, generally 0.6–2.5 m tall. Root system reported to penetrate to a depth of 11.5 m and has a lateral extension of 10 m, exploiting about 850 m^3 of soil (Sadeq *et al.,* 2014) and reported to improve soil calcium and phosphorus concentration (Karim *et al.,* 2009). As a xerophytes, *L. py*rotechnica is well adapted to grow in extremely severe climatic conditions (-0.4 to 49.5 ^{0}C) of tropical and sub-tropical arid regions of the world. The strong soil binding property of this species, due to its extensive and long root system, makes the species as a prime choice in sand dune fixation and desert afforestation programs (Sharma and Chouhan, 2008; Mathur and Sundaramoorthy, 2018). Besides its regulatory services, this species is also serving many provisional (medicinal) and cultural services (Mathur and Sundaramoorthy, 2013a). Apart from all these uses, it also serves as good quality fodder (Karakilcik and Kalyar, 2014) and provides protein, dietary fiber, calcium, phosphorus, iron and vitamin C to animals (Goyal and Sharma, 2009). In Indian desert, it is browsed to some extent by all stock, but especially by camels (Ram, 2016).

Phyto-sociological studies of this species were conducted earlier from hyper arid biosphere reserve area in north Africa (Shaltout *et al.,* 2010), Wadi Gimal, Red sea coast region of Egypt (Galal, 2011), Algeria (Bouchneb and Benhouhou, 2012), Indian hot arid region (Singh *et al.,* 2012; Mathur and Sundarmoorthy, 2013b), Cholistan desert of Pakistan (Nisar *et al.,* 2013) and Jazan region of Suadi Arabia (Salman, 2015). El-Amier *et al.* (2015) studied its relationships with soil properties like water holding capacity, electric conductivity and chlorides in the Egyptian desert. Ebad *et al.* (2011) had explored the metabolic adjustment strategies in this species during dry and wet conditions from the eastern desert of Egypt. Recently, Mathur and Sundaramoorthy (2019) reported its distribution and succession trends at various land forms and land uses of the arid and semi-arid regions of the Thar desert. On Sandy undulating buried pediments *Haloxylon salicornicum, Ziziphus nummularia, Lasiurus sindicus*, and *Panicum antidotale* are its major associates. While at sandy plain its mainly associate with *Crotalaria burhia*.

Despite of its many phyto-sociological observations, there is very little information's on the interactive effects of plant community dynamics and soil properties on spatial distribution, density and canopy volume of this species and indeed, there has not been any study conducted from the Indian hot arid region. Therefore, this study addresses the information gap's pertaining to distribution types and with its traits (density and canopy volume) under the null hypothesis (H_0) that these attributes are independent to the site properties. Thus the objectives of the present study were (a) to evaluate the spatial distribution of this species along with its density and canopy volume at different sites, and (b) to empirically examine the effects of community dynamics and soil properties on these two variables.

Materials and Methods

Present study was conducted at nine arid sites of the Indian Thar desert during the year 2017-18 (Table 1). These sites are related to older alluvial plain landform and are currently utilized as open grazing lands. The sites were selected based on pre-defined ecological criteria's pertaining to presence of the species, population size of the species for quadrats study, species associates and soil composition of the sites. The authenticity of the *L. pyrotechnica* were cross checked with the flora of the India arid region (Bhandari, 1978) as well as with the herbarium sheets available at Plant Ecology Section of ICAR-Central Arid Zone Research Institute, Jodhpur, India.

Vegetation sampling: To study the population dynamics of this species, 10 quadrats (10 x 10 m) were laid down at each site, (Kent and Coker, 1992). Ecological attributes like density, frequency, abundance and relative importance values were quantified (Curtis and McIntosh, 1950). Quantification and interpretation of other community parameters (woody perennial richness, Shannon and Weaver index and evenness) were carried out by using standard methodology (Ludwig and Reynolds, 1988). Canopy volume was quantified though using upper half spheroid geometric equations and express as 4/3 Π r^2 x h (Ludwig *et al.,* 1974) where *r* and *h* denotes radius and height of the shrub, respectively.

Dispersion indices: Three different dispersion indices, namely Lloyd's mean crowding, Morisita index of dispersion, and Smith and Wilson were quantified. The indices were selected based on their mathematical inheritance that deals with mean crowding, degree of aggregation and variance in abundance, respectively. These indices were quantified according to Ludwig and Reynolds (1988) by using simple Microsoft Excel program. The mathematical expression of these indices is as follows:

1. Lloyd's mean crowding (X^*): It was quantified by using two parameters, i.e., the mean density of plant per quadrate and their negative binomials (which were calculated through arithmetic mean, variance and square root of their products). The value of this index 0 or <1 indicates uniform; 1 = random and >1 clumped (Mathur, 2014b). Further, standard error of mean crowding was estimated by using the following formula:

$$S.E = \frac{\bar{X}}{K^2}\sqrt{\left[var\left(\widehat{K}\right)\right] + \frac{\widehat{K}\left(\bar{X}+\widehat{K}\right)\left(1+\widehat{K}\right)^2}{q\bar{X}}}$$

Where var $\widehat{K}$ = Sampling variance for negative binomial k, q = Number of quadrates counted.

2. Morisita's index: The parameters like number of sample units (n), number of individuals in each sample unit and the total number of individuals in n sample were used for the calculation of Moristia's index. Mathematically they can be represented as:

$$I_\delta = \frac{n\sum x_i\ (x_i - 1)}{N(N-1)}$$

Because Morisita's index can be used to calculate for different quadrate sizes, the scale of analysis is not inherent, and it can be used to investigate pattern over a range of densities and scales (Kristensen *et al.,* 2006). The value of this index equal to 1 indicates random, more than one indicates aggregated, and less than one uniform distribution.

***3. Smith and Wilson index*:** This index is based on the variance in the abundance of the species. Here, variance measured over the log of the abundance in order to use proportional differences rather than absolute differences in abundance (Mathur, 2014b). Following equation was used for calculation of this index.

$$E_{var} = 1 - \frac{2}{\pi} arctan \frac{\left\{\sum_{i=1}^{s}[1n(n_1) - \sum_{i=1}^{s}\frac{1n(n_j)}{s}]\right\}^2}{S}$$

Where the arctangent is measured as an angle in radians and Evar = Smith and Wilson's index of evenness, ni = Number of individuals in the species i in the sample, nj = Number of individual in species j in the sample, S = Number of species in the entire sample. A value of <1 indicates the clumped pattern to 1 for uniform and >1 for random pattern.

***Soil analysis*:** Soil samples from 0-30 cm depth were collected from all the sites studied. Samples were air-dried, ground in wooden pestle and mortar. These ground soil samples were passed through 2-mm sieve for physico-chemical properties. Processed soil samples were analyzed for particle size distribution (Piper, 1950), and other soil characteristics such as pH and EC following standard procedures (Jackson, 1973). Organic carbon was determined following Walkley and Black method, available phosphorus by Olsen extraction method, estimated colorimetrically and available potassium was estimated by flame photometry as described by Jackson (1973).

***Statistical analysis*:** Preliminary, canonical correlation analysis (CCoA) was conducted to elucidate the possible relationships of soil and community variables with spatial patterns, density and canopy volume of this species. Following this, two steps partial least square (PLS) regression was carried out to develop the model equation. In the first step, the significant predictors were identified with the concept of variable importance for the projection (VIPs) and under this any predictive variable with a VIP value greater than 1 was considered as a highly significant predictor (Onderka *et al.,* 2012). Then the second step PLS was conducted with significant variables (X) only, and the results were interpreted through model qualities, bi-plot relationships between exploratory (X) and dependent factors (Y) and finally model equations for different dependent variables (spatial patterns, canopy volume and density) were developed.

Results and Discussion

***Population and soil features*:** The Indian desert spreads across the state of Rajasthan and parts of Gujarat in western India and covers about 200000 km^2. About 61% of the Indian desert is in Rajasthan state covering 12 districts. In this region, the number of tree species are very limited and the dominated shrubs are *L. pyrotechnica*, *Calligonum polygonoides*, *Calotropis procera*, *Acacia jacquemontii*, *Ziziphus nummularia* etc (Nawal *et al.,* 2006; Khalik *et al.,* 2013). Many of these species are suffering from over-exploitation for their varying uses resulting in shrinkage of their habitats and loss of land phytomass. Singh *et al*. (2012) studied productivity and carbon storage capacity of *L. pyrotechnica* in three agro-climatic zones in the Indian Desert. According to them this species showed compartmentalization in carbon and nitrogen accumulation probably an adaptation mechanism of this species. Conclusively, *L. pyrotechnica* has significant impacts on plant population dynamics, basal area, biomass production and carbon accumulation, as well as helps in stabilizing wind prone soil in this region. Removal of this species under over-exploitation not only leads to land degradation, but also affects the ecology and carbon stock of the arid soil (Mathur and Sundaramoorthy, 2018). Thus ecological studies of this species, specifically pertains to spatial pattern behavior and its relationships with various bottom-up and top-down factors have paramount importance for this arid zone.

Different attributes were quantified in this study (Table 2). Woody perennial species richness ranged from four (Jhund and Chainpura) to eight (Jhalamaliya and Pooniyo ka bas). Shannon and Weaver index that measured the species diversity of a community and its higher value represented higher diversity which normally approached 3 or more and rarely exceeded to 4.5 and lower value indicated the lower diversity. In this study it was recorded 1.24 (Chainpura) to 1.76 (Jhalamalitya and Kapoordi). Contrasting to species richness, evenness which measured the relative abundance and distribution of the species and in the present study it was ranged from 0.59

Table 1. Geo-reference of studied sites

	Chaba	Shergah	Jhalamaliya	Kapoordi	Nandiya	Guman Singh	Jhund	Chainpura	Pooniyo ka bas
N	26^0 22' 1.9"	26^0 20' 7.6"	26^0 31' 54.5"	25^0 54' 27.8"	26^0 30' 47.5"	26^0 21' 3.7"	25^0 59' 44.7"	26^0 04' 24.9"	25^0 18' 19.5"
E	72^0 07' 57.8"	72^0 16' 40.9"	73^0 24' 31.6"	71^0 23' 35.2"	73^0 22' 31.2"	72^0 13' 4.5"	71^0 57' 12.2"	71^0 58' 26"	71^0 28' 37.1"

N: Latitude; E: Longitude

Table 2. Attributes studied at various sites

Parameters		Chaba	Shergah	Jhalamaliya	Kapoordi	Nandiya	Guman Singh	Jhund	Chainpura	Pooniyo ka bas
Community	Richness	7	6	8	7	5	5	4	4	8
parameters	Shannon index	1.39	1.50	1.76	1.76	1.37	1.28	1.31	1.24	1.41
	Evenness	0.59	0.82	0.75	0.89	0.81	0.80	0.95	0.89	0.60
	Sand (%)	92.80	89.70	90.00	91.80	88.00	90.50	91.50	91.70	92.80
	Silt (%)	2.70	3.50	4.50	2.70	4.00	3.60	3.20	3.30	2.20
Soil	Clay (%)	4.50	5.80	5.50	5.50	8.00	5.90	5.30	5.00	5.00
parameters	pH	8.68	8.65	8.63	8.86	8.72	8.60	8.82	8.80	9.12
	EC (d S m^{-1})	0.06	0.14	0.07	0.40	0.08	0.07	0.10	0.10	0.22
	OC (%)	0.06	0.08	0.01	0.13	0.10	0.06	0.06	0.04	0.05
	P (kg/ha)	5.20	5.20	2.50	11.50	3.25	5.70	3.70	3.80	17.50
	K (kg/ha)	140.00	182.00	80.00	260.00	212.00	135.00	161.00	132.00	153.00
	Canopy volume (sq.m)	0.52	0.39	1.66	0.41	3.06	0.34	3.99	1.75	2.56
	Density/ha	20.00	75.00	10.00	150.00	130.00	30.00	330.00	150.00	30.00
Attributes	Lloyd's index with SE	2.70±	3.61±	4.34±	5.18±	3.52±	3.63±	5.62±	3.85±	3.10±
of Lpp.		0.93	0.80	0.79	0.84	0.96	0.83	0.84	0.76	0.80
	Morisita index	1.00	1.06	1.08	1.04	1.00	1.11	1.06	1.04	0.78
	Smith and Wilson index	0.91	0.96	0.86	0.98	0.98	0.93	0.99	0.98	0.93

Lpp: Leptadenia pyrotechnica; EC: Electric conductivity; OC: Organic carbon; P: Phosphorus; K: Potassium; SE: Standard error

(Chaba and Pooniyo ka bas) to 0.95 (Jhund). Interestingly, we got higher evenness at Jhund that showed lowest richness amongst selected sites (Table 2) suggested that total number of individuals at this particular site quite evenly distributed among the four species. Higher canopy volume (3.99 sq.m) of *L. pyrotechnica* was recorded at Jhund site followed by Nandiya (3.06 sq.m) and the lowest was recorded at Guman Singh (0.39 sq.m) and Shergah (0.39 sq.m) sites. The highest density of this shrub was also recorded at Jhund (330/ha.) while only 10 and 20 plants/ha was recorded at Jhalamaliya and Chaba sites, respectively.

Synchronization of *L. pyrotechnica* density with community evenness suggested that this species having the niche sharing tendency with other associates and thus, can be utilized for rehabilitation of the degraded lands with species having similar trait values. This finding supported by the work of Collet *et al.* (2014) where they quantified the joint effects of density and species evenness on productivity and species coexistence with *Fagus sylvatica* and *Acer pseudoplatanus* as model species. Their results suggested that mixtures of these two functionally similar species had the highest production at maximum evenness, indicating a complementary effect between them. In present study *Ziziphus nummularia* and *Aerva persica,* were the major co-occurring species thus, the management or planting schedules for sandy habitats with such types of associate will enhance the system stability.

In present study, there was higher proportion of sand followed by clay and silt. However, a proportion of clay/silt was recorded double at Kapoordi and Nandiya sites. Further soil electric conductivity (d S m^{-1}) ranged from 0.06 (Chaba) to 0.40 (Kapoordi) while, minimum organic carbon (0.04 %) was recorded at Chainpura site and maximum (0.13 %) at Kapoordi site. Higher values of phosphorus (kg/ha) and potassium (kg/ha) were also recorded at Kapoordi site.

***Spatial patterns*:** Clumped spatial distribution of this species can be declared on the basis of Lloyd's and Smith and Wilson indices. The values of Lloyd's index recorded more than one suggesting clumped pattern, while for Smith and Wilson index <1 values were recorded that also indicated clumped pattern. However, Morisita index revealed the random pattern of this species expect at Pooniyo ka bas where uniform pattern was recorded (Table 2). The highest value of Lloyd's index (5.62) was recorded at Jhund site followed by Kapoordi (5.18), while the least clump pattern with this index was recorded at Chaba (2.70). The standard error of this index ranged from 0.76 to 0.96 (Table 2). Thus majority of indices suggested the clumped pattern of this species, while Morisita index suggested random type. Such types of variations were due to mathematical inheritance of these indices.

Sagar *et al.* (2003) reported that the distribution of *Boswellia serrata, Holarrhena antidysenterica* and *Lannea coromandelica* changed from clumped to uniform and the distribution of *Butea monosperma, Cassia fistula* and *Elaeodendron glaucum* changed from uniform to clump as the degree of disturbance increased. Our present results suggested that at highly homogenous community this species acted as a gap filler and had the tendency to occupy the bare patch more rapidly than other could do. Suggesting as the community diversity decreases, this species transforms its distribution into random and subsequently might be into uniform one. However, such types of interpretation should be supported with seed germination and dispersal strategies of this species at field conditions. But one fundamental fact can be mentioned here that other associates of this species like *Z. nummularia* having higher ecosystem values (food, fodder and medicine) compared to this species, thus, such associate might have larger direct anthropogenic pressure (cut and carry) and creating clumped conditions for *L. pyrotechnica.* Lower or moderate grazing intensity and clumping pattern could be explained by the findings of Wang *et al.* (2010) who suggested that higher consumption rate of preferred species occurred in sheep with the situation under low preferred species (non-palatability of *L. pyrotechnica* in the present case) followed a clumped pattern. The clumped distributions of less preferred species are always beneficial for herbivore to search and consume favored one, thus, higher grazing activity at site/habitat indicates clumped pattern of non-preferred or non-palatable species. Hence, the clumped pattern in relation to grazing frequency might be the resultant action of patchy grazing (i.e. selection of palatable and avoid unpalatable species). Further, dominance of clumped type distribution tendency had also been explored for species belongs to other arid areas of the world like *Bouteloua eriopoda*, Chihuahuan Desert, New Mexico (Alvarez *et al.,* 2011), *Carangana stenophylla* of semi-arid areas of Mongolia (Xie *et al.,* 2015) and they linked such patterns with precipitation, nurse effect and species interaction types (competition/facilitation).

Effects of soil and community properties: In present study, cumulative percentage in CCoA analysis suggested that first four axes together accounted 80% variability (Table 3). Squared cosines were used to link the variable with the corresponding axis and the greater the squared cosine, the greater the link with the corresponding axis. With respect to interpretation criteria of CCoA bi-plot (closeness, orthogonal and opposite locations of different variables, Mathur and Sundaramoorthy, 2008), certain specific relationships were visualized (Fig 1) and the correlation matrix between dependent and exploratory variables were recorded (Table 4). It was observed that randomness (Morisita) of this species was negatively related with soil pH (r^2 = -0.84) and with soil phosphorus (r^2 = -0.68). However, the clumped pattern (Smith and Wilson) was positively related with soil organic carbon (r^2 = 0.67) and with soil potassium (r^2 = 0.71). It was also observed that species richness and evenness were working in opposite directions for the density of this species and for clumped spatial pattern (Smith and Wilson index). Richness affected them in a negative manner (r^2 = - 0.67 and r^2 = -0.69, respectively). While evenness was positively related to density (r^2 = 0.76) and with clumped pattern (r^2 = 0.66, Smith and Wilson and r^2 = 0.79, Lolyd's). The density of this species was also interrelated with clumped spatial type distribution of this species pattern (r^2 = 0.76, Smith and Wilson and r^2 = 0.75, Lolyd's).

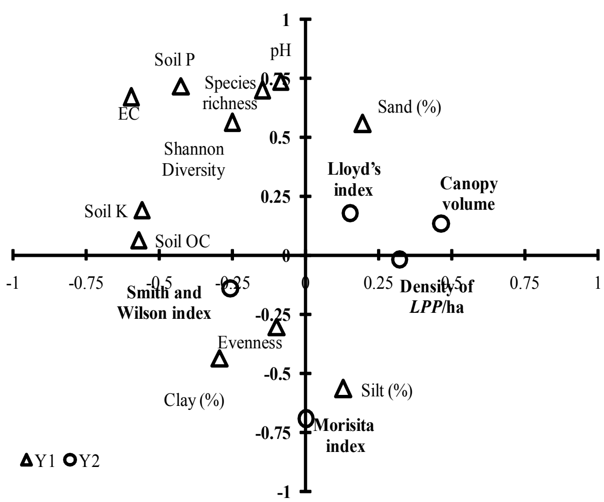

Fig 1. Canonical correlation analysis

Among the soil variables, clumped pattern (Smith and Wilson Index) enhanced with soil organic carbon and potassium suggesting the facilitation behaviour of fertile patches for seedling emergence and establishment (Maestre *et al.,* 2005; Wang *et al.,* 2013) and can also be supported with some of the previous studies conducted from this region for *Corchorus depressus, Blepharis sindica* and for *Tribulus terrestris* by (Mathur and Sundaramoorthy, 2008; 2012; Mathur, 2014a). On the other hand, randomness (Morisita Index) of this species showed negative relationships with soil pH and soil P which further suggested that there might be some indirect factors forcing this species toward adopting clumped distribution. Here it could be assumed that after germination both these two might act as deciding factors. Mathur (2016) in their habitat specific study suggested that vivipary habit of *Tephrosia purpurea* commanding its clumped pattern and after germination conditions like acidic soil, high C/N ration and availability of the bare surface area were responsible for its further pattern types. Similarly electric conductivity was the most crucial factors for post germination establishment at older alluvial plain (OAP) and piedmont. Additionally, after germination, particularly community dynamics like woody perennial richness diversity and concentration of dominance were key controlling factors for clumped pattern of *T. purpurea* at piedmont and younger alluvial plan (YAP). Further, in either side oscillation of these factors from a threshold level would facilitate its uniform pattern at both the habitats. Such gaps can also be evaluated for *L. pyrotechnica.*

Species diversity can be divided into two main components: 'richness', which represents the number of species in a given area, and 'evenness', which represents the variability in species abundances (Magurran, 2004). In this study, species richness was positive and negatively related to diversity (r^2 = 0.71) and evenness (r^2 = - 0.69). When using the species richness as a single measure of species diversity, it is traditionally assumed that (a) species richness is positively correlated with evenness, and (b) species richness accounts for much of the spatial and temporal variance in diversity (Mathur and Sundaramoorthy, 2012). These assumptions suggested that relationships between species richness and evenness are consistent between species assemblages, and that the two components represent different interpretations of a coherent ecological property known as diversity. Empirical studies have tested the assumption that species richness and evenness are positively correlated (Mouillot *et al.,* 2013), and whether inconsistencies in relationships between the two components can compromise the efficacy of compound indices (Farmilo *et al.,* 2014). Empirical studies reveal that the relationship between species richness and evenness is not always positive (Manier and Hobbs, 2006). Species evenness and richness also differ in their responses to local habitat factors (Ma, 2005; Wilsey and Stirling, 2007), suggesting that the two diversity components may vary independently and be influenced by different ecological processes. Ma (2005) found no consistent patterns between species richness and evenness, with the two components having different responses to edaphicfactors. In this studey, we found no significant linked among diversity variables and soil components. However, the richness and density of *L. pyrotechnica* were negatively (r^2 = - 0.67) related with each other, thus, indicating that this species controls the stand community composition. Stand richness also facilitates the randomness of this species as its found negative with clumped nature.

Table 3. Component variability and correlations between input variables and canonical variables (Y_1 and Y_2) of CCoA

Parameters	F1	F2	F3	F4
Variability (%)	20.000	20.000	20.000	20.000
Cumulative %	20.000	40.000	60.000	80.000
Sand (%)	0.197	0.556	-0.514	0.164
Silt (%)	0.131	-0.567	0.494	-0.076
Clay (%)	-0.292	-0.438	0.558	-0.249
pH	-0.085	0.737	0.133	-0.187
EC (d S m^{-1})	-0.595	0.669	0.086	0.371
OC (%)	-0.570	0.064	0.050	0.354
P (kg/ha)	-0.424	0.715	-0.104	-0.197
K (kg/ha)	-0.559	0.191	0.074	0.354
Richness	-0.148	0.698	-0.195	-0.345
Shannon diversity	-0.251	0.561	0.180	0.198
Evenness	-0.097	-0.306	0.539	0.709
Density of *L. pyrotechnica*/ha	0.319	-0.014	0.396	0.612
Canopy volume of *L. pyrotechnica*	0.465	0.135	0.623	-0.360
Lloyd's index	0.150	0.182	0.586	0.775
Morisita index	-0.001	-0.695	0.051	0.548
Smith and Wilson index	-0.255	-0.138	0.170	0.438

Table 4. Canonical correlation among the studied parameters

Vari-ables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	-0.82														
3	-0.90	0.55													
4	0.55	-0.73	-0.26												
5	0.33	-0.56	-0.13	0.58											
6	-0.20	-0.27	0.46	0.13	0.63										
7	0.55	-0.78	-0.28	0.83	0.71	0.25									
8	-0.12	-0.35	0.39	0.27	0.71	0.98	0.33								
9	0.27	-0.20	-0.28	0.24	0.34	-0.13	0.53	-0.10							
10	-0.08	0.17	-0.02	-0.04	0.52	0.16	0.16	0.18	**0.71**						
11	-0.35	0.32	0.28	-0.18	0.16	0.33	-0.40	0.34	**-0.70**	-0.03					
12	-0.01	-0.07	0.10	0.20	0.14	0.32	-0.21	0.37	**-0.67**	-0.25	**0.77**				
13	-0.18	0.10	0.34	0.46	-0.20	-0.13	-0.01	-0.06	-0.24	-0.29	0.11	0.47			
14	-0.04	0.15	0.01	0.06	0.37	0.23	-0.15	0.27	-0.28	0.32	**0.80**	**0.75**	0.18		
15	-0.35	0.58	0.11	**-0.84**	-0.32	-0.05	**-0.68**	-0.17	-0.43	0.00	0.52	0.09	-0.49	0.33	
16	-0.09	-0.28	0.28	0.27	0.34	**0.67**	0.04	**0.71**	**-0.69**	-0.38	**0.67**	**0.76**	0.23	0.38	-0.04

1. Sand (%), 2. Silt (%), 3. Clay (%), 4. pH, 5. EC (d S m^{-1}), 6. OC (%), 7. P (kg/ha), 8. K (kg/ha), 9. Species richness, 10. Shannon and Weaver diversity index, 11. Species evenness, 12. Density of *L. pyrotechnica*/ ha, 13. Canopy volume of *L. pyrotechnica,* 14. Lloyd's index, 15. Morisita index, 16. Smith and Wilson index; Bold numbers represents the significant relationships

VIPs for each exploratory variable with PLS 1 were assessed (Table 5). This method allowed us to identify which exploratory variable that contributed most to the model. Any independent variable with a VIP value greater than 1 was considered as a highly important predictor (Onderka *et al.,* 2012). Among the studied parameter, pH, potassium and organic carbon, evenness and species richness were identified as significant predictors (VIPs>1.0, Fig 2). The Q^2 cumulated index measures the global goodness of fit and in the present study, with the significant VIPs the Q^2 for studied parameter remained low (0.43), even with sixth components (ideally it should be close to 1). This suggested that quality of fit varied a lot on the depended variables. The cumulated R^2Y and R^2X corresponds to the correlation between the exploratory (X) and dependent (Y) variables with the component close to 1 with 4th component generated by PLS summarize well both by X_S (0.99) and the Y_S (0.75) for the studied parameters. After eliminating non significant predictors the model equations for individual parameter were as follows:

Density of *L. pyrotechnica*/ha = -7192+824.22 x soil pH+5170 x OC (%) - 20.6 x soil P (kg/ha)-3.03 x soil K (kg/ha) + 0.02 x species richness + 450.40 x evenness (r^2 = 0.86).

Canopy volume of *L. pyrotechnica* = -182.60 + 21.92 x soil pH + 203.92 x OC (%)-0.52 x soil P (kg/ha) - 0.13 x soil K (kg/ha) + 0.40 x species richness + 1.96 x evenness (r^2 = 0.89).

Clumped pattern $_{\text{Lloyd's}}$ = - 64.61 + 7.06 x soil pH + 95.81 x soil OC (%) -0.13 x soil P (kg/ha) -0.06 x soil K (kg/ha) + 0.54 x species richness + 10.95 x evenness (r^2 = 0.88).

Random pattern$_{\text{Morisita}}$ = 6.78-0.68 x soil pH + 3.98 x OC (%) + 0.01 x soil P (kg/ha) - 0.007 x soil K (kg/ha) - 0.041 species richness + 0.62 x evenness (r^2 = 0.95).

Clummped$_{\text{Smith and Wilson index}}$ = 1.44-0.06 x soil pH-2.8 x OC (%) +0.002 x soil P (kg/ha) + 0.002 soil K (kg/ha) - 0.02 x species richness—0.021x evenness (r^2 = 0.99).

Above results revealed that this species preferred and flourish in sandy habitats and some of the site properties significantly affected its distribution type, cover and density. Thus, rejecting our null hypothesis. We found no relationship between canopy volume and spatial pattern of this species and which were in contrary to the study of Tao and Zhang (2013) who utilized cover and above ground biomass for predicting the spatial pattern and plant to plant interactions for *Seriphidium terrae-albae* and *Artemisia songarica* and suggested that cover and above ground biomass had strong spatial complexities. Further, canopy volume could also be linked with the fact that this trait having importance in photosynthesis and evapo-transpiration (Vacchiano *et al.,* 2011) and being a arid zone species this leafless species can adopt this type of distribution to avoid excess evapo-transpiration and latent heat (Mathur, 2014c).

Table 5. Variable importance in the projection (VIP) assessed with PLS 1

Variable	F1	F2
Evenness	2.0901	1.8219
Richness	1.6970	1.4697
K (kg/ha)	1.1747	1.0859
pH	0.2767	1.0691
OC (%)	1.0922	0.9708
P (kg/ha)	0.4879	1.0391
Silt (%)	0.0312	0.7408
EC (d S m^{-1})	0.5682	0.6443
Sand (%)	0.2886	0.4583
Shannon	0.4660	0.4446
Clay (%)	0.4900	0.4246

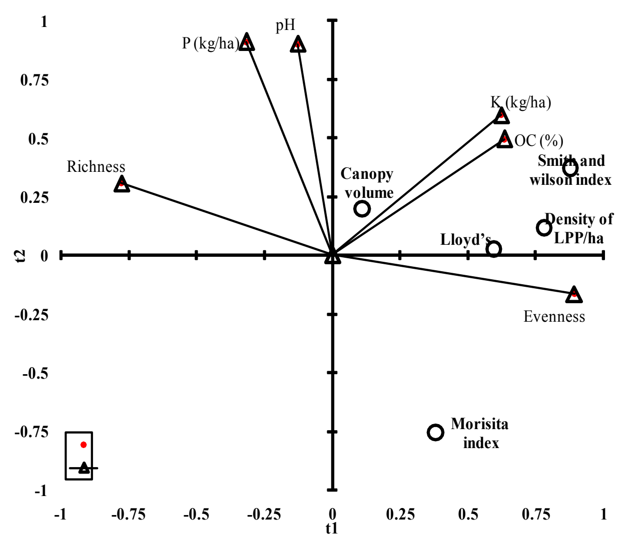

Fig 2. Partial least square regression bi-plot with significant VIPs

Conclusion

Present study provided dominant clumped distribution pattern of this species which were directly under the influence of the various bottom-up and top-down factors. However, gaps pertain to its seed transmission (role of mechanical barriers as seeds have the characteristic silky pappus hairs for dispersal), seedling distribution and establishment with relation to spatial distribution of *L. pyrotechnica* need further exploration.

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