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Kinetic of nutrient uptake and their utilization efficiency in a seratonious plant-*Blepharis sindica*

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Efficiency of plant nutrient uptake and use span multiple levels of biological organization from leaves to ecosystems are significantly affected with both spatial and temporal events. Plant communities on nutrient-poor soils are thought to use nutrients more efficiently to produce biomass than plant communities on nutrient rich soils. Yet, increased efficiency with declining soil nutrients has not been demonstrated empirically in semi arid areas where nutrient uptake and their utilization efficiency thought to be strongly affected with soil nutrient conditions with various pulse, inter-pulse and non-pulse events. In present investigation net nutrient uptake (P, Na, K, Ca and Fe) by a desert lignified seratonious plant *Blepharis sindica* and its nutrient utilization efficiency (NUE) were assessed spatially and with specific seasonal events. ANOVA analysis revealed that all the factors undertaken in the present investigation (i.e. site, seasonal event and the interaction between them) affects P, Na, K, and Ca nutrient uptake (J) and their nutrient utilization efficiency ($P<0.001$), however, for iron, interaction between site and event were recorded non-significant. Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity proves the usefulness of factorial analysis used in this study. Path analysis with community parameters revealed that this plant seems to be a better nutrient efficient only when it plays a key stone species role in a community. Further its relative importance value below 40 seems to be a threshold for net uptake of calcium. Uni-model (hump back) relationships if net uptake of P and Ca and NUE of P and Na with soil organic carbon were established. 80-90 mg 100g^{1} soil organic carbon largely supports the net uptake of phosphorus and calcium and nutrient utilization efficiency of phosphorus and sodium. On the other hand higher organic carbon (150-165 mg 100g^{1}) played an inhibitory factor for them. Soluble and insoluble sugars showed monotonic positive relationships with and net uptake of calcium and iron.

Key words : Net uptake of nutrient**,** Nutrient utilization efficiency, Spatial and temporal events, Principal component analysis, Path analysis

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INTRODUCTION

The ion influx concerned with the relationship between the demands of the growing plant and the uptake of ion by its root, and with the process involved within the plants. Nutrient uptake depends on nutrient supply to the root surface and active absorption by root cells (Claasen and Steingraobe, 2002). It is influenced by various factors associated with (a) the edaphic factors such as nutrient concentration in soil solution, soil water content, soil temperature, soil compaction, mycorrhizal symbiosis (Chapin, 1980; Engels, 1993; Arvidsson, 1999; Lehmann, 2003) soil pH (Godbold *et al.*, 2003), access to water (Bouillet *et al.*, 2002), and water logging (Santiagon, 2000). (b) The spatial or site factors includes stand age (Bouillet *et al.*, 2002), and species composition (Davis *et al.*, 2004, Silva and Rego, 2003). (c) The temporal factors also influenced nutrient uptake and their utilization mechanisms, in the tropic, changes of climatic conditions during the year are less pronounced than in other region and are usually characterized by dry and rainy seasons (Soethe *et al.*, 2006). Here, seasonal changes in soil water content may affect nutrient uptake activity of root (Lehmann 2003; Ray and Singh, 1995).

The term nutrient use efficiency widely used as a measure of the capacity of a plant to acquire and utilize nutrients for production of timber, crops or forages. Definition of nutrient efficiency varies greatly (Gourley *et al.*, 1994). With regards to yield parameters, nutrient efficiency has been defined as the ability to produce a high plant yield in a soil or other media that would otherwise limit the production of a standard line (Graham, 1984 and Gourley *et al.*, 1994). Alternatively, nutrient utilization efficiency is generally defined as total plant biomass produced per unit nutrient absorbed, which is equivalent to the reciprocal of nutrient concentration in entire plant (Baliger *et al.*, 1990). Overall nutrient use efficiency in plants is governed by the influx of ions form the soil to the root surface and by the influx of ions to roots followed by their transport to the shoots and remobilization to plant organ (Jothimani *et al.*, 2007). Rengel (2002) correlated utilization efficiency with environmental factors as well as with the genotype x environment interaction. Valle and Rosell (2000) studied the mineral composition of perennial vegetation of shrub patches in Patagonia, Argentina. They have assessed the spatial and temporal variability's of 15 minerals in *Atriplex lampa* and *Prosopis appataw*. They explained that variations in each minerals element may be due to species composition, site sampling and seasonal pattern.

In unproductive desert habitats, water availabilities are often highly pulsed, with both frequent and irregular water availability (Knapp and Smith, 2001). The importance of this irregularity to plant growth and/ or survival is often considered in term of inter-year or inter-seasonal variation winter versus spring rainfall (Welzin and McPherson, 2000). Plants in arid and semi arid systems are primarily limited by water but nutrient may be co-limiting. Summer precipitation pulses can affect eco-physiological parameters directly by increasing soil water availability and also by effects on nutrient availability (Synder *et al.,* 2004). Many short term isotopic and eco-physiological studies have demonstrated that desert plant species, functional groups and life stages differs in the capacity to use summer resources pulse (Schwinning et al., 2002 and Ivans *et al.*, 2003). From the Indian Thar desert eco-physiological studies for *Pennisetum typhoides* and *Lasiurus sindicus* were carried out by Huber *et al.* (1973). Sanklha *et al.,* (1975) studied ecophysiological paramters for *Aerva* spp., *Blepharis sindica*, *Anticharis, Schima* spp. Kasera and Mohammad (2010) describes the ecology and adaptive strategies of some halophytes like *Cressa critica, Aleuropus lagopoides, Suaeda fruticosa*. Review of literature reveled the scanticity of information with regards to variation in kinetic of nutrient uptake and their utilization efficiency due to various spatial and temporal events in semi arid climate of the Indian Thar Desert. The present study was aimed with following objectives (1) to evaluate the impacts of different spatial patterns (Site) and temporal events (Pulse to Inter-pulse events and from Inter-pulse to Non Pulse events) on the nutrient uptake (J) and their utilization efficiency (NUE) of Na, K, P, Ca and Fe in non - cultivated medicinal plant *Blepharis sindica* at natural sites, (2) to evaluate the relationships of various soil parameters (soil organic carbon, nitrogen, phosphorus, soil moisture, electric conductivity and pH), community dynamics (Relative importance value of *B. sindica*, richness herbaceous plants, Shannon Weiner index (H'), Simpson index and Evenness) and plant metabolites (Total carbohydrate, soluble and in-soluble sugar) with J and NUE of various nutrient and (3) Path analysis to predict the relation types between various independent and dependant parameters.

Blepharis sindica. It is locally known as 'Bhangari" is a small serotinous (retention of seeds on parent plant; Lamnot, 1991), dichotomously branched and woody annual having short stem, sessile leaves and fruit in form of capsule. Each capsule having two seeds and each seed covered with hygroscopic hairs on its surface. The survivorship pattern showed high mortality during early phase of life cycle that associated with per cent moisture availability, accordingly Aziz and Khan (1993) considered this plant under type III Deevey curve. Narita (1998) have studied the germination, growth, phenology, and survivorship strategies and seed production in *B. sindica*. Phyto-chemistry, clinical validation and agro-techniques have been studied by Mathur and Sundaramoorthy (2005).

RESEARCH METHODOLOGY

Site selection and their status:

Within the 16 km radius of Jodhpur, Rajasthan, India two different sites have been selected for this endangered medicinal plant (Table A). Each site was differentiating from each other in respect of their soil composition, land uses, and their vegetation status. During the study period mean annual precipitation ranges from 0.004 to 260 mm, average winter (January) temperature ranges from 10.7 to 23^0C while, mean summer (June) temperature ranges from 28.7 to 42.2^oC. Relative humidity ranges from 31 to 91% (Morning) and 08 to 68% (Evening).

Biomass estimation:

The above and belowground biomasses of the *B. sindica* were estimated by using random sampling at different sites. The plants were uprooted in fix numbers (ten) and then washed using mild tap water for remove foreign material. Then the harvested materials were separated in root and shoot (stem, leaves, and capsules), air-dried and weighed using electronic balance (accuracy 0.001 g.). The sampling were carried out during three distinct environmental conditions *i.e.* monsoonal period (July; rainy season), post- monsoonal period (December, cool season) and pre- monsoonal period (May,

Table A : GPS locations, habitat types and other attributes of sampling sites

Site No.	Coordinates		Habitat	Soil textures			
	N	E		Clay	Silt	Sand	Gravel
1.	$26^0\ 15'\ 1.8''$	$73^0\ 59'\ 29.8''$	Old alluvium plains	29.6	1.35	68.7	0.255
2.	$26^0\ 12'\ 29.5''$	$73^0\ 04'\ 24.8''$	Hummock undulating terrains	28.5	4.33	76.0	1.105

Hot season). With every sampling the uprooted plant for next sampling were identified and marked with aluminum tag. In present investigation the Pitman method (based on relative growth rate) was used to quantify nutrient uptake during various sampling period. Therefore, the sampling carried out during monsoonal and post monsoonal called event 1, while the sampling during post monsoonal and pre monsoonal called as event 2.

Nutrient quantification:

Various macro (Na, K, Ca and P) and micro (Fe) nutrients were quantified. K, Na, Ca were estimated by flame photometer. The dry plant material were digested with tri-acid mixture ($10HNO_3$: $1H_2SO_4$: $4HClO_4$) and the results are expressed in mg g^{-1}. The standards of potassium, sodium and calcium were prepared by using KCl, NaCl and $CaCO_3$, respectively. Phosphorus was estimated by spectroscopic method (Allen *et al.*, 1976) based on the development of molybdenum blue colour. The standard was prepared with KH_2PO_4. The iron content has been quantified by the Atomic Absorption Spectrophotometer. These macro and micro nutrient were selected according to their potential role in medicinal property (aphrodisiac activity) of this plant.

Nutrient uptake and relative growth rate:

The rate of net uptake (J) can be partitioned in to net uptake to shoot (J_s) and net uptake to root (J_R) (Pitman, 1975). ($J= J_S+J_R$)

The net nutrient uptake by shoot (1) and by root (2) were calculated by following formulas.

$$J_S = W_S/W_R * X_S*R_W \qquad \_\_\_\_(1)$$

$$J_R = X_R * R_W \qquad \_\_\_\_(2)$$

The relative growth rate was calculated by following formula :

$$Rw = \frac{(\log B_2 - \log B_1)}{T_2 - T_1}$$

The W_S and W_R are the weight of shoot and root; X_S and X_R are the relative content of ion in shoot and root; R_W is the relative growth rate (Biomass of whole plant). B_2 and B_1 are dry weight of plant at time T_2 and $T_{1.}$ The nutrient utilization efficiency index (NUE) was made according to Siddiqi and Glass (1981), by using the following formula:

$$NUE = \frac{(\text{Dry weight of plant})^2\ (\text{mg})^2}{\text{Each nutrient content}\ (\text{mg}^{-1})}$$

The variability of nutrient uptake (J) and NUE were quantified at two levels *i.e.* spatial (at two sites) and during two temporal event, (1) when the soil have adequate moisture due to preceding rains (rain to winter) and (2) when the soil lack the moisture due to evo-transpiration from soil surface (winter to summer).

The analysis of variance (ANOVA) was carried out in a two way strip – plot design. The strip-plot sacrifices precision on the main effects of both factors. The interaction is measured more accurately by this method than is possible with either a randomized complete block or a split-plot design (Gomez and Gomez, 1984).

Multivariate analysis:

To assess the suitability of factor analysis two tests namely Bartlett's test of sphericity and Kaiser-Meyer-Olkin (KMO) were carried out. Principal component analysis (PCA) was carried out as a data reduction techniques. PCA was performed with Pearson correlation coefficient. Main objective of PCA analysis was to find out the relationships of nutrient uptake (whole plant, by shoot and by root) and their utilization efficiency with various parameters related with edaphic (organic carbon, nitrogen, phosphorus, moisture, pH and electric conductivity), community dynamics (Herbaceous richness, relative importance value of *B. sindica* Shannon and Weiner index, Simpson index and evenness) and plant metabolites (carbohydrate, soluble and in-soluble sugar). Other parameters related with biomass (RGR, Ws/W_R and root/ shoot ration), relative contents of various nutrient in shoot and root (Xs/X_R) were also assessed.

Appropriate regression equations were selected on the basis of probability level significance and higher R^2 value. This path analysis was carried out with Curve Expert software (2001).

Research Findings and Analysis

Nutrient supply and acquisition are two of the most important factors that control plant productivity and diversity, as growth is generally limited by the availability of inorganic nutrients in the soil. From a biochemical point of view, all plant species should need the same quantity of nutrients to construct a given amount of tissue. However, differences do exist in tissue concentration because of heterogeneous distribution of nutrients in the soil and varying uptake efficiency.

During study period range of various parameters (Edhapic factors, community dynamics and plant metabolites) at *B. sindica* locations are presented in Table 1. The maximum (0.642) relative growth rate (RGR) was observed at site one during event 1 (Table 2). However, the minimum (0.03) RGR was observed during the event 2 at different sites *i.e.* 2. At both sites plants showed higher RGR during event 1. The maximum shoot: root biomass ratios (W_S/W_R; 10.05) was observed at site one during event 1 (Table 2). However, the minimum W_S/W_R (5.21) ratio was observed during the event 1 at site two. The high ratio of W_S/W_R indicates that during event 1 (*i.e.* when the moisture and other environmental conditions are more favorable) plant invest their resources

Table 1 : Various parameters at *B. sindica* location during study period

	Parameters	Range
Soil parameters	Organic carbon (mg $100g^1$)	72.05-160.4
	Nitrogen (mg $100g^1$)	55.11-79.37
	Phosphors(mg $100g^1$)	12.62-45.51
	Moisture	0.705-6.23
	pH	6.3-7.48
	Electric conductivity	0.13-0.17
Community composition (1x1 m) quadrate	Richness	3-8
	Shannon weiner index (H')	0.97-1.86
	Simpson index	0.17-0.4
	Evenness	0.91-0.98
	Relative importance value of *B. sindica*	23.77-46.25
Plant metabolite	Total carbohydrate	168.7-257.9
	Soluble carbohydrate	118..2-163
	In-soluble carbohydrate	50.46-94.84

more in above ground parts whereas during event 2 plant invests their resources in below ground parts. This finding is supported by both empirical and the theoretical observation that suggests that there are trade-offs in the way plant allocate biomass to root: under low resource conditions plants increase their biomass allocation to roots at the expense of leaves and shoots to increase nutrient uptake (Boot and Mensink, 1990; Aerts *et al.*, 1991; Ryer and Lambers, 1995; Reynolds and D'Antonio, 1996; Fransen and Berendse, 1998; Mc-Connaughay and Coleman, 1999 and Brilz and Biondini, 2002). ANOVA analysis revealed that variations in RGR brought by both site and event factors as well as by their interaction (Table 2), however, temporal events were non-significant for W_S/W_R.

Range of relative content of nutrients in shoot and root are presented in Table 3. Except iron maximum net uptakes (J) of various nutrients (P = 84.44; Na = 4.76; K = 32.31; Ca = 13.2) were recorded at the site 1during event 2 (Table 4). However, the maximum uptake of iron (1.18) was recorded at same site (1) but during event 1. The minimum uptake of P (3.4), Na (0.59), Ca (3.1) and Fe (0.13) were recorded during the same event (2) but at similar site two. This indicates that uptake variability of P, Na, K and Ca are largely influenced by spatial factor because the maximum and minimum content of these elements were recorded during the similar event but at different sites (Table 4). Maximum uptake of phosphorus during inter-pulse to non-pulse events can be explained by the facts that drying increase the release of P from air –dried soil and sediments (Sparling *et al.*, 1985 and Qiu and McComb, 1995), further microbial turnover also associated with increase in available P (Rao and Tarafdar, 1992 and He and Zhu, 1998).

The maximum Js/J_R ratio of P (941.3) K (1114), Ca (100) and Fe (126.3) were recorded at site 1 during event 1 while, Js/J_R ratio for sodium (80.13) and Ca (134.2) were recorded maximum at same site but during event 2. The minimum J_S/J_R ratio for P (82.4), K (269.1) were observed during event 2 but

Table 2 : Relative growth rate and shoot root weight ratio

Spatial factor	Temporal factors	Relative growth rate	W_S/W_R
Site 1	Event 1	0.642	10.05
	Event 2	0.217	7.94
Site 2	Event 1	0.08	8.05
	Event 2	0.03	5.21
ANOVA results/source of variation			
Site	Sum of square	0.435	22.90
	Computed F	2570**	191.98**
Seasonal events	Sum of square	0.160	0.004
	Computed F	548.15**	0.84^{NS}
Site x seasonal events	Sum of square	0.107	23.63
	Computed F	1739.08**	264.29**

** indicates significance of value at P<0.01

at site two. While for Ca (68.77) and iron (13.69), Js/J_R were recorded minimum during same event (2) but at different site (one). These results revealed that during moisture stress condition P, K, Ca and Fe are held back more in root compared to shoot. Minimum J_S/J_R ratios for Na (28.8) were recorded during event 1 at site 2 (Table 4).

For accurate prediction of plant and ecosystem response to global climatic changes requires a better understanding of the mechanism that control acquisitions of growth limiting resources (Bielenberg and Bassirirad, 2005). Plant species and functionally related species from arid and semi arid habitats vary in their capacity to take up summer precipitation, and acquire nutrients quickly after summer precipitation and subsequently respond with eco-physiological changes (Synder *et al.*, 2004). In present investigation, analysis of variance (ANOVA) revealed that all the factors undertaken in the present investigation (*i.e.* site, seasonal event and the interaction between them) affects P, Na, K, and Ca nutrient uptake (J) at the 99% probability levels (Table 6). Seasonal events and its interaction with site factors brought significant variation in Fe uptake at 99% probability level, while site factor alone was recorded non-significant for it.

Increased nutrient use efficiency in plants is vital to enhance the yield and quality of crops, reduce nutrient input cost and improve soil, water and air quality. Plant species and cultivars within species differ in absorption and utilization of nutrient and such differences are attributed to morphological, physiological and biochemical processes in plants and their interaction with climate, soil, fertilizer, biological and management practices.

A complete assessment of ecosystem productivity and nutrient dynamics requires measuring above and below ground patterns of biomass increment, nutrient content and turnover. In fact, a proper evaluation of nutrient use efficiency

Table 3 : Range of relative content of various nutrients in root and in shoot (mg g^{-1})

	Phosphorus	Sodium	Potassium	Calcium	Iron
Root	0.73-1.65	0.269-1.85	0.13-2.37	0.25-2.63	0.125-2.95
Shoot	16.40-68.37	2.64-3.56	1.85-62.11	5.94-21.14	0.5-3.41

Table 4 : Nutrient uptakes (J) from whole plants and shoot root uptake ratio (Js/J_R)

Spatial factor	Temporal factor	Phosphorus		Sodium		Potassium		Calcium		Iron	
		J	Js/J_R Ratio	J	Js/J_R Ratio	J	Js/J_R Ratio	J	Js/J_R Ratio	J	Js/J_R Ratio
Site 1	Event 1	44.1	941.3	2.05	49.07	23.27	1114	11.7	100	1.18	126.3
	Event 2	84.4	374.3	4.76	80.63	32.31	799.6	13.2	68.77	0.86	13.69
Site 2	Event 1	23.7	357.2	1.52	28.86	10.22	928.2	8.78	134.2	1.41	142.5
	Event 2	3.4	82.4	0.59	36.15	12.5	269.1	3.1	86.29	0.13	17.97

Table 5 : Utilization efficiency index at various spatial and temporal events

		Phosphorus	Sodium	Potassium	Calcium	Iron
Site I	Event 1	27.7	163.7	14.2	33.4	486.3
	Event 2	34.9	244.9	132.2	86.8	787.6
Site II	Event 1	1.15	19.8	2.8	6.05	64.05
	Event 2	1.3	20.35	7.05	12.15	68.05

Table 6 : ANOVA

Parameters	ANOVA Results/ Source of variation	Phosphorus		Sodium		Potassium		Calcium		Iron	
		Sum of square	Computed F value	Sum of square	Computed F value	Sum of square	Computed F value	Sum of square	Computed F value	Sum of square	Computed F value
J	Site	7780.06	724253**	19.55	564.97**	819.72	40946**	142.96	1474.12**	0.399	13.58^{NS}
	Seasonal events	294.92	5807.69**	1.14	14.29**	90.75	1804.42**	9.15	40.03**	2.60	29.34**
	Site x seasonal events	0.591	9089.31**	10.12	347.73**	31.16	173.45**	0.006	1308.64**	0.59	19.22**
NUE	Site	2726	301793**	10192.1	3261**	14017.2	29965.8**	7767	21154.9**	977671	8690.4**
	Seasonal events	39.85	2633.21**	4975	6368**	11225.9	718458.6**	2673.36	23101.1**	69928.8	5594.3**
	Site x seasonal events	5988.14	1799.15**	4798	13350**	9665.6	133751.9**	1673	23101.4**	66298.1	1.70^{NS}

** indicates significant of value at P=0.01; NS = Non-significant requires data at the whole-plant level, because patterns of aboveground utilization efficiency are not necessarily similar to whole-plant utilization efficiency (Aerts and Chapin, 2000). However most of the previous studies have focused exclusively on the nutrient utilization efficiency (NUE) of fine-litter production (Vitousek, 1984; Silver, 1994; Yasumura *et al.*, 2002; Paoli *et al.*, 2005). One whole plant NUE study from semiarid grassland in northern china was conducted by Yuan *et al.* (2006).

The results of NUE are presented in Table 5. In this experiment it was observed that all the studied elements showed higher NUE during event 2 at site 1. However, there minimum concentrations were recorded during event 1 at site 2. At this point it can be interpreted that this plant seems to more nutrient utilize efficient with depleted resources. The theory of nutrient use efficiency suggested that nutrient efficiency increases uni-modally with declining soil resources. Vitousek (1982) developed the theory of nitrogen use efficiency and according to it plant communities on the N-poor soils are less productive, but more efficient in their use of N that communities on N-rich soils. Further comparisons at species (Vazquez de Aldana and Berendse, 1997; Eckstein and Karlsson, 2001), community (Nakamura *et al.*, 2002; Silla and Escudera, 2004), and at ecosystem level (Hiremath and Ewel, 2000), nitrogen use efficiency increases as soil N availability declines. Most of the studies related with utilization efficiency of various nutrients so far exclusively addressed the species in lowland mires, subarctic tundra, or tropical rain forest (Yuan *et al.*, 2006), while few such studies have also been conducted in the semi arid region of the world, particularly northern China (Yuan *et al.*, 2005).

Table 7 : Bartlett's sphericity and Kaiser-Meyer-Olkin sampling adequacy tests

Chi-square (Critical value)	315.749
DF	276
p-value	0.001
Alpha	0.05
KMO	0.553

Table 8 : Multivariate analysis

	F_1	F_2	F_3
Eigenvalue	15.204	6.779	2.017
Variability (%)	63.350	28.247	8.403
Cumulative %	63.350	91.597	100.000
J P	0.895	0.002	0.102
NUE P	0.988	0.003	0.009
J Ca	0.732	0.215	0.054
NUE Ca	0.871	0.074	0.055
J Na	0.809	0.005	0.186
NUE Na	0.999	0.001	0.000
J K	0.981	0.019	0.000
NUE K	0.774	0.037	0.189
J Fe	0.053	0.823	0.124
NUE Fe	0.994	0.003	0.003
RIV of *B. sindica*	0.004	0.965	0.032
Richness	0.761	0.234	0.006
Simpson index	0.176	0.238	0.085
Shannon index	0.726	0.258	0.016
Evenness	0.169	0.639	0.392
Organic carbon	0.845	0.080	0.075
Phosphorus	0.700	0.260	0.039
Nitrogen	0.809	0.031	0.160
pH	0.878	0.014	0.108
Electric conductivity	0.890	0.000	0.110
Moisture	0.325	0.667	0.007
Soluble sugar	0.758	0.169	0.073
Insoluble sugar	0.039	0.954	0.008
Total carbohydrate	0.128	0.790	0.082

Variables bold and underlined with Eigen vectors (coefficients) >±0.70 are considered

ANOVA analysis revealed that variation in NUE of P, Na, K and Ca brought by site, events and by their interaction ($P<0.01$), but for iron, interaction between site and event were recorded non-significant.

Multivariate analysis:

Result of Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity are presented in Table 7. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy is an index used to examine the appropriateness of factor analysis. A high value (between 0.5 and 1.0) indicates factor is appropriate, value below 0.5 imply that factor analysis may not be appropriate. In this study KMO is 0.553 (Table 7), therefore, we can proceed with our factor analysis. For Bartlett's test of sphericity there are two levels to interpret this test (a) H0: There is no correlation significantly different from 0 between the variables and Ha: at least one of the correlations between the variables is significantly different from 0. As the computed p-value is lower than the significance level = 0.05, one should reject the Null hypothesis H0 and accept the alternate. In other words it can be concluded that there are significant relationships between our variables.

PCA is an ordination technique that constructs the theoretical variable that minimizes the total residual sum of squares after fitting straight lines to the data (Jafari *et al.*, 2004). PCA is also known as exploratory factor analysis and it's a data reduction techniques designed to represent a wide range of attributes on a smaller number of dimensions. The PCA analysis was performed with the use of Pearson correlation coefficient and the results presented in Fig. 1. The interpretation of the correlation circle was carried out under

Table 9 : Correlation matrix between net nutrient uptake (J) and NUE of various nutrients

Sr. No.		J P	NUE P	J Ca	NUE Ca	J Na	NUE Na	J K	NUE K	J Fe
1.	J P									
2.	NUE P	0.912								
3.	J Ca	0.906	0.854							
4.	NUE Ca	0.945	0.890	0.727						
5.	J Na	0.986	0.849	0.838	0.960					
6.	NUE Na	0.949	0.991	0.847	0.942	0.906				
7.	J K	0.935	0.975	0.787	0.965	0.906	0.993			
8.	NUE K	0.898	0.753	0.632	0.969	0.951	0.835	0.870		
9.	J Fe	0.375	0.246	0.698	0.051	0.297	0.213	0.108	0.006	
10.	NUE Fe	0.958	0.982	0.839	0.959	0.925	0.998	0.996	0.864	0.196

Values in bold are different from 0 with a significance level alpha=0.05

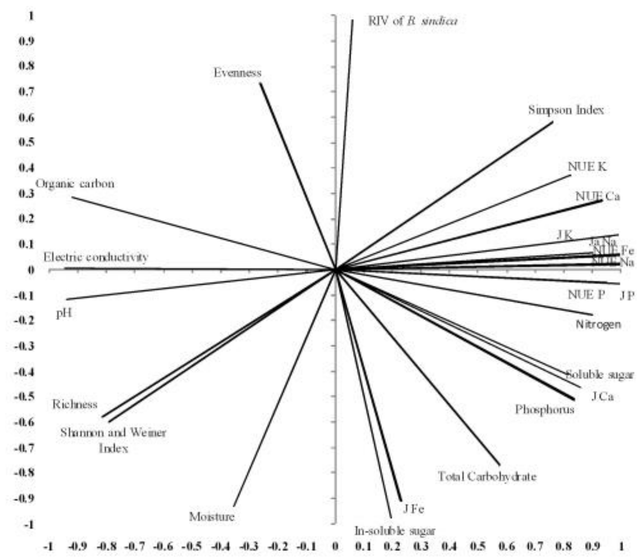


Fig. 1 :Correlation bi-plot of principal component analysis

following criteria, when two variables are far from the center, then if they are: close to each other, they are significantly positively correlated (r close to 1); if they are orthogonal, they are not correlated (r close to 0); if they are on opposite side of the center, then they are significantly negatively correlated (r close to -1). 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 (Fig. 1).

Principal components were considered useful if their cumulative percentage of variance approached 80 per cent (Wei-Giang *et al.*, 2008). In present study the first three principal components (PC1, PC2 and PC3) together accounted 100 % of the total variance in data set (Table 8) with their individual contribution being 62.35 per cent, 28.49 per cent and 8.403, respectively.

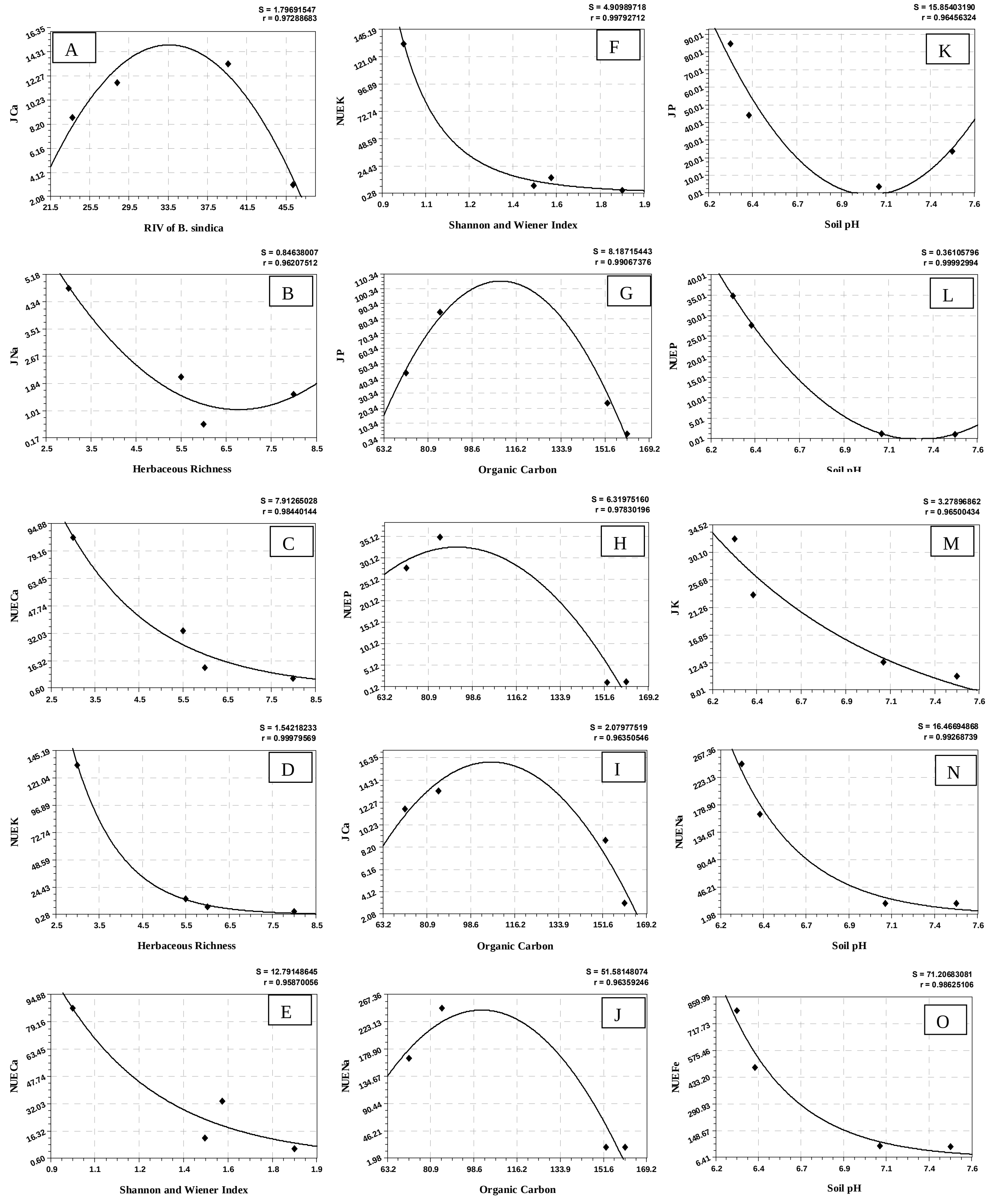
On each component, variable with loading >0.70 were identified as significant variable and used for path analysis (Iwara *et al.*, 2011 and Mathur, 2012). It has been found that among 24 different variables, 21 variables were significant. NUE of all the elements and except iron the net nutrient uptake of all other nutrients are well correlated with F_1 component (Table 8 and Fig. 1). Among community dynamics and soil parameters herbaceous richness, Shannon and Wiener index, organic carbon, phosphorus, pH, nitrogen and electric conductivity are related with component F_1. While relative importance of *B. sindica*, evenness, moisture, insoluble and total carbohydrate are well related with F_2 component.

Correlation analysis :

From present study, correlation circle (Fig. 2) as well as Table 9, revealed that Net uptake (J) of phosphorus was positively related with net uptake of Na (r = 0.986*) and NUE of Fe (r = 0.958*). On the other hand NUE of Phosphorus related with NUE of Na (r =0.991**) and Fe (r = 0.981*) as well as with net uptake of K (r = 0.975*). For calcium NUE related with net uptake of Na (r = 0.960*) and potassium (r = 0.965*) and with NUE of potassium (r = 0.969*) and iron (r = 0.959*). Synergistic relationships have also been observed between J Na with NUE of K(r = 0.951*) and between net uptake (J) of K with NUE Fe (r = 0.996**). Similarly nutrient utilization efficiency of Na showed positive relation with net uptake of potassium (r = 0.993**) and with NUE of iron (r = 0.998**). These significant correlations were observed at 0.01% (**) and 0.05% (*) levels.

Path analysis:

Despite the importance of NUE a clear understanding of major mechanism and inheritance of NUE is lacking (Basra and Goyal, 2002). Part of this is due to the inheritance complexity of NUE, as it's a function of multiple interacting genetic and environmental factors (Dawson *et al.*, 2008). Most of the environmental and NUE interactions studies were carried out on popular crops with man managed ecosystem however, less


A
S = 1.79691547
r = 0.97288683
J Ca
RIV of B. sindica
16.35
14.31
12.27
10.23
8.20
6.16
4.12
2.08
21.5
25.5
29.5
33.5
37.5
41.5
45.5
F
S = 4.90989718
r = 0.99792712
NUE K
Shannon and Wiener Index
145.19
121.04
96.89
72.74
48.59
24.43
0.28
0.9
1.1
1.2
1.4
1.6
1.8
1.9
K
S = 15.85403190
r = 0.96456324
J P
Soil pH
90.01
80.01
70.01
60.01
50.01
40.01
30.01
20.01
10.01
0.01
6.2
6.4
6.7
6.9
7.1
7.4
7.6
B
S = 0.84638007
r = 0.96207512
J Na
Herbaceous Richness
5.18
4.34
3.51
2.67
1.84
1.01
0.17
2.5
3.5
4.5
5.5
6.5
7.5
8.5
G
S = 8.18715443
r = 0.99067376
J P
Organic Carbon
110.34
100.34
90.34
80.34
70.34
60.34
50.34
40.34
30.34
20.34
10.34
0.34
63.2
80.9
98.6
116.2
133.9
151.6
169.2
L
S = 0.36105796
r = 0.99992994
NUE P
Soil pH
40.01
35.01
30.01
25.01
20.01
15.01
10.01
5.01
0.01
6.2
6.4
6.7
6.9
7.1
7.4
7.6
C
S = 7.91265028
r = 0.98440144
NUE Ca
94.88
79.16
63.45
47.74
32.03
16.32
0.60
2.5
3.5
4.5
5.5
6.5
7.5
8.5
H
S = 6.31975160
r = 0.97830196
NUE P
35.12
30.12
25.12
20.12
15.12
10.12
5.12
0.12
63.2
80.9
98.6
116.2
133.9
151.6
169.2
M
S = 3.27896862
r = 0.96500434
J K
34.52
30.10
25.68
21.26
16.85
12.43
8.01
6.2
6.4
6.7
6.9
7.1
7.4
7.6
D
S = 1.54218233
r = 0.99979569
NUE K
Herbaceous Richness
145.19
121.04
96.89
72.74
48.59
24.43
0.28
2.5
3.5
4.5
5.5
6.5
7.5
8.5
I
S = 2.07977519
r = 0.96350546
J Ca
Organic Carbon
16.35
14.31
12.27
10.23
8.20
6.16
4.12
2.08
63.2
80.9
98.6
116.2
133.9
151.6
169.2
N
S = 16.46694868
r = 0.99268739
NUE Na
Soil pH
267.36
223.13
178.90
134.67
90.44
46.21
1.98
6.2
6.4
6.7
6.9
7.1
7.4
7.6
E
S = 12.79148645
r = 0.95870056
NUE Ca
Shannon and Wiener Index
94.88
79.16
63.45
47.74
32.03
16.32
0.60
0.9
1.1
1.2
1.4
1.6
1.8
1.9
J
S = 51.58148074
r = 0.96359246
NUE Na
Organic Carbon
267.36
223.13
178.90
134.67
90.44
46.21
1.98
63.2
80.9
98.6
116.2
133.9
151.6
169.2
O
S = 71.20683081
r = 0.98625106
NUE Fe
Soil pH
859.99
717.73
575.46
433.20
290.93
148.67
6.41
6.2
6.4
6.7
6.9
7.1
7.4
7.6

Contd. Fig. 2

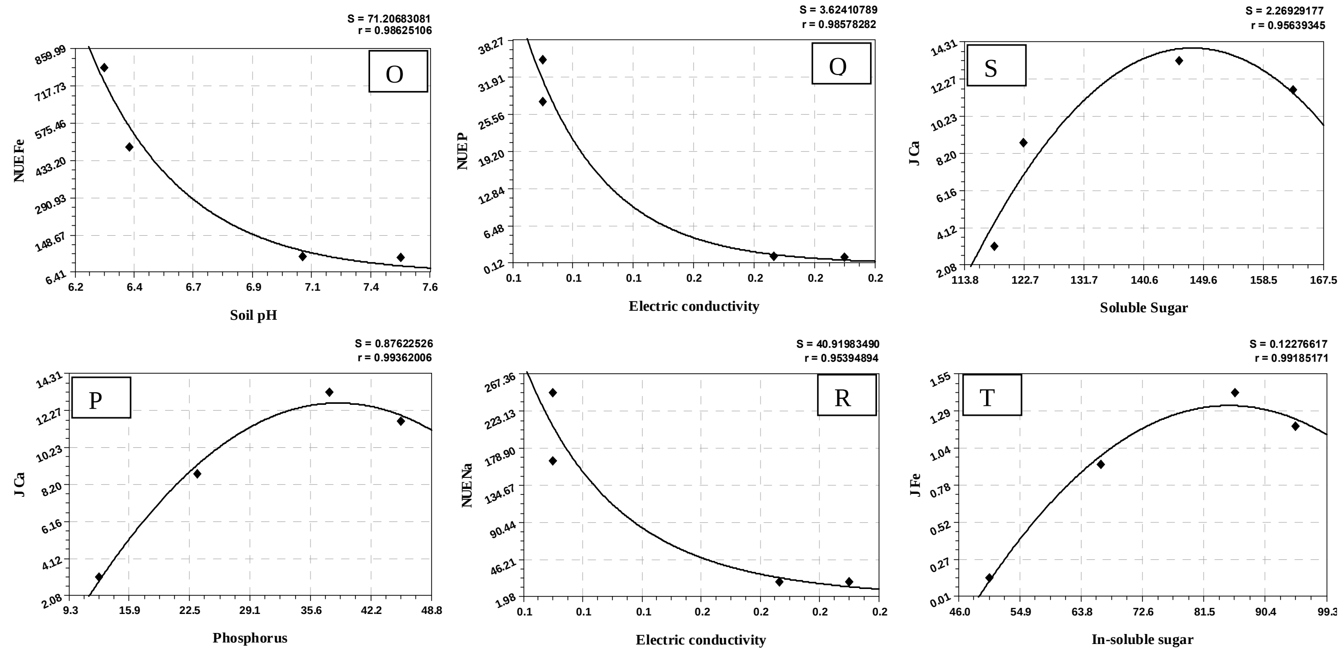


Fig. 2 :Path analysis between various exploratory and dependent variables

is known about controlling factors associated with NUE in wild plants. Hiremath and Ewel (2000) compare the plant level nutrient use efficiency and soil nutrient supply for predicting ecosystem nutrient use efficiency. According to them ecosystem use efficiency is subjected to control by both bottoms up (related to characteristic of the species involved) and top up factors (related to an environmental factor: soil fertility). In this paper an attempt has been made to find out the controlling factors associated with J, NUE of various nutrients by utilizing the path analysis using curve expert software (2001).

Community dynamics:

Relative importance value of *B. sindica* showed a unimodel relationship with net uptake of calcium (J Ca = -65.03+4.75 RIV of *B. sindica* + -0.070 RIV of *B. sindica*$^{\wedge 2}$ (R^2 = 0.972* ±1.79; Fig. 2A). Herbaceous richness revealed quadratic relation with net uptake of Na (J Na = 13.20 + -3.59, herbaceous richness+0.265 herbaceous richness ^2, R^2 = 0.962*±8.46; Fig. 2B). It also showed a negative exponential relations with NUE of calcium (NUE Ca = 383.70e^ (-0.493 herbaceous richness, R^2 = 0.984*± 7.92; Fig. 2C) and with NUE of potassium (NUE K = 2062.31e^ (-0.915 herbaceous richness, R^2 = 0.99**±1.54; Fig. 2D).

Diversity indices gave valuable information's about community status. Higher Shannon and Wiener index (H') value indicated that many species are represented by the same number while; low value indicates complete dominance of one species. In present investigation Shannon and Wiener index exhibited negative exponential and power relationships with NUE of calcium (NUE Ca = 971.63e^(-2.49 Shannon and Wiener index, R^2 = 0.958*±12.79; Fig. 2E) and potassium (NUE K = 111.40 Shannon and Wiener index ^-5.62, R^2 = 0.997**±4.90; Fig. 2F), respectively.

Efficient utilization of nutrients might be a factor that contributes to the pattern of species occurrence in patchy environment (Yuan *et al.*, 2006). Pausas and Austin (2001) have concluded that worldwide most of the grassland studies and most fertilization experiments showed a downward trend in species richness. In present investigation both herbaceous richness and diversity parameter (H') revealed monotonic reverse relation with NUE of Ca, Na, K and net uptake of sodium. From community parameters it can be interpreted that this plant seems to be better nutrient efficient only when it plays a key stone species role in community. Further its RIV value below 40 seems to be a threshold for net uptake of calcium. This finding is supported by the fact that under natural condition this plant regarded as calciferours (Mathur, 2005).

Edaphic factors:

Nutrient use efficiency in any plant governs by productivity (biomass) and nutrient content in different manners *i.e.* its linearly related with biomass and inversely related with nutrient content in plant (Baligar *et al.*, 2001). Thus any soil factors that govern the NUE in any fashion exhibited its influence on biomass production and the nutrient content with in plant.

Soil organic carbon:

Effects of soil organic matter (SOM) on nutrient dynamics and how they impact NUE have been reported by several authors (Baligar and Fageria, 1997). The SOM helps to maintain good aggregation and increase water holding capacity and exchangeable K, Ca, and Mg. It also reduces P fixation. In present path analysis it was observed that soil organic carbon inhibited the net uptake of phosphorus (J P = -394.052+9.103 organic carbon+-0.041 organic carbon^2, R^2 = 0.990**±8.18; Fig. 2G) and their utilization efficiency (NUE P = -31.225+1.38Organic Carbon+-0.007Organic Carbon^2, R^2 = 0.978*±6.31; Fig. 2H) quadratic fashion.

Organic carbon also held back the net uptake of calcium (J Ca = -30.18+0.865 organic carbon+-0.004 organic carbon ^2, R^2 = 0.963*±2.07; Fig. 2I) and NUE of sodium (NUE Na = -505.74+14.71+organic carbon+-0.0723 organic carbon ^2, R^2 = 0.963±51.5; Fig. 2J) in similar quadratic fashion.

Thus in this study uni-model (hump back) relationships of net uptake of P and Ca and NUE of P and Na with soil organic carbon were established. 80-90 mg $100g^1$ soil organic carbon largely supports the net uptake of phosphorus and calcium and nutrient utilization efficiency of phosphorus and sodium. On the other hand higher organic carbon (150-165 mg $100g^1$) played an inhibitory factor for them. These findings can be correlated with the sand loving properties of this plant (Mathur, 2005 and 2012). This plant avoids clay content (which is the better source of soil organic carbon compare to sand) for their initial establishment and subsequent growth (Mathur and Sundarmoorthty, 2005).

Soil pH:

Soil pH exhibited negative quadratic relationships with net uptake of phosphorus (J P = 6872.74+-1952.31 soil pH+138.62 soil pH^2, R^2 = 0.964*±15.85; Fig. 2K) and its nutrient utilization efficiency (NUE P = 1904.39+-522.83 soil pH+35.88 soil pH^2, R^2 = 0.999**±0.361; Fig. 2L). Soil pH also showed negative exponential relation with net uptake of potassium (J K = 18735.49 e^ (-1.024 soil pH, R^2 = 0.965*±3.27; Fig. 2M) and nutrient utilization efficiency of sodium (NUE Na = 3.71+009+e^(-2.63 soil pH, R^2 = 0.992**±16.46; Fig. 2N) and iron (NUE Fe = 1.432+010e^(-2.66 soil pH, R^2 = 0.986*±7.10; Fig. 2O). Here it can be concluded that pH 6.2 to 6.5 is the crucial factor for nutrient utilization of various nutrients.

Soil phosphorus:

Soil phosphorus supports the net uptake of calcium in quadratic fashion (J Ca = -8.894+1.11 phosphorus+-0.01 phosphorus^2, R^2 = 0.99**±0.876; Fig. 2P). This finding revealed monotonic positive relationships between soil available P and net uptake of calcium.

Electric conductivity:

Nutrient utilization efficiency of phosphorus (NUE P = 4909316.2e^ (-92.023 electric conductivity, R^2 = 0.985±3.62; Fig. 2Q) and sodium (NUE Na = 7962e-007 electric conductivity^-9.49, R^2 = 953*±40.91; Fig. 2R) showed negative exponential and power relations with electric conductivity, respectively. This salinity inhibits the NUE of phosphorus and sodium of this plant.

Plant metabolites:

Soluble and insoluble sugars showed quadratic positive relationships with and net uptake of calcium (J Ca = -224.85+3.23 soluble sugar+-0.01 soluble sugar^2, R^2 = 0.95±2.25; Fig. 2S) and iron (J Fe = -5.975+0.171 in-soluble sugar+-0.001 in-soluble sugar^2, R^2 = 991**±0.122; Fig. 2T), respectively. This relation is explained by the correlated between sucrose transportation and calcium and iron uptake (Hammond and White, 2008; 2011, Philip and Veneklaas, 2012).

Conclusion:

The capture and efficient use of limiting resources influence the competitive success of individual plant species as well as species diversity across resource gradients. The adaptive use of limited resources by a plant is one of the key factor that determine species persistence in a community. From present investigation it can be concluded that *Blepharis sindica* fulfill the theory of nutrient use efficiency that suggests the nutrient efficiency increases unimodally with decline soil resources. From nutrient dynamics and their utilization efficiency it can be interpreted that this plant is well adapted for patchy environment where it can play a key stone species role more specifically on sandy soils.

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