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DIRECTIONS OF VARIATION OF EDAPHIC ENVIRONMENT IN HALOPHYTIC VEGETATION OF HIGHLY SALINIZED AND WATERLOGGED AREAS OF HYDERABAD DISTRICT. SINDH, PAKISTAN

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ABSTRACT

A direct gradient analysis of averaged edaphic data for 0 - 60 cm pedon depth of twelve highly salinized, waterlogged and relatively undisturbed sites of Hyderabad District (Sindh), Pakistan, was performed through Principal Components Analysis in order to determine the main directions of compositional variation of the edaphic environment and the relationship between the vegetation pattern and the environmental complex. The first principal component was largely governed by salinity and clay contents, the second component correlated with available P and silt content and the third component associated with sulphate content and pH. The distribution behaviour of *Salvadora persica, Tamarix indica, Suaeda monoica, Suaeda fruticosa and Cressa cretica* along the gradients is examined.

Key words: Halophytic vegetation, edaphic environment, principal component analysis

INTRODUCTION

The vegetation of highly salinized and waterlogged areas of Hyderabad District (Sindh), Pakistan, exhibits local variation of growth of diverse halo-physiotypes due to local differences in physiographic conditions primarily affected by the soil salinity and climatic aridity The phenomenon of surface salinity and sodicity is highly prominent in these soils which is generally true for most the arid saline areas where either local run-off collected in basin evaporates with heat or the capillary fringes of the underground water come in direct contact with the superficial soil layer due to water logging that evaporates leaving behind evaporite-deposits of salts. These soils are generally alluvial and fine-textured and are basic in reaction. Salinity and sodicity of surface (0-20cm) and sub-surface (20-40 & 40-60cm) soil samples are of very high order (9.9-120.0 $dS.m^{-1}$) – generally high in surface samples.. The ionic contents are very high - Na and Cl ions being predominant - up to 951 and 1177 meq/l, respectively. These soils have low K and P (Khan *et al.,* 2003). In this paper, main directions of the compositional variation of halo-catenae associated with highly saline and waterlogged areas of Hyderabad District and the relationship of the vegetation pattern with the environmental complex have been investigated.

Description of the area:

The Area of Hyderabad District falling between 68°E and 69°E longitudes and 25°N and 26°N latitudes is located **(Fig.1)** in the lower Indus Valley of Eastern Valley Section of Sindh, constituting the arid floodplain above the delta. The physiography and geology of the area is described by Pithawalla (1959) and climatic details have been discussed in Khan *et al.* (2003).

MATERIALS AND METHODS

In order to calculate the axes of environmental stand-ordination, the technique of Principal Component Analysis (PCA) was adopted (Legendre and Legendre, 1983; Ludwig and Reynolds, 1988; Orloci and Kenkel, 1992) that has widely been used in ecological studies (Auclair *et al*., 1976; Yabe and Numata, 1984; Shaukat and Uddin, 1989; Bernaldez *et al.,* 1989; Shaukat, 1994; Chaghtai *et al*., 1995; Zaidi *et al*., 2000; Mashaly *et al.*, 2001; Jafri *et al.,* 2003; Vaughan and Ormerod, 2005). The PCA program was run on data of edaphic variables averaged for 0-60 cm-soil layer, which have already been published elsewhere (Khan *et al*., 2003). Correlations among the edaphic variables defined the broader groups of edaphic variables.

RESULTS AND DISCUSSION

Halophysiotypes:

The plants of salinized habitats are variously classified taking into account their chemistry, ecological and habitat characteristics, morphology and physiology. An eco-physiological approach as a compromise between above approaches is adopted by Breckle, (1986). His halo-physiotypes include stem-succulents (S), leaf succulents (L), recretohalophytes (X), pseudohalophytes (P) and non-halophytes (N). In highly saline and waterlogged areas of Hyderabad District where salinity ranged from 9.9 to 120 $dS.m^{-1}$ only L, X and P types of halo-physioytpes were present. There were 6 leaf succulents, 4 recretohalophytes and 7 pseudo-halophytes in all (Table 1). Stem succulents and non-halophytes are absent. It appears that unlike coastal salt marshes of Pakistan, S type halophytes are not present in our inland salinized and waterlogged habitats (cf. Khan and Ahmad, 1992). The occurrence of pseudo-halophytes in highly saline waterlogged soils is of ecological interest. All pseudohalophytes recorded here are known to occur in many halophytic communities of Pakistan coast (Khan, 1987). Presumably, conditions for their early growth are improved by rainfall which leaches a good deal of salts out of the top layers of the soil (cf. Heurtex, 1970) reducing the danger of the salinity during early stages of the plant life or these species are differentially salt tolerant to certain extent. Kassas and Zahran (1967) have also reported the occurrence of some nominal glycophytes like *Aerva javanica***,** *Ochradanus baccatus* and *Asphodelus tenuifolius* in diverse habitats of littoral salt marsh of Red sea coast of Egypt.

Directions of compositional variation of edaphic environment:

The directions of compositional variation of edaphic environment were determined by calculating axes of Q-type stand ordination through PCA in which average soil characteristics were the attributes to the stands. The program was run on edaphic variables averaged for 0-60 cm soil layer. The PCA is an efficient technique that generates a set of uncorrelated variables (the principal components) that are linear combinations of the original variables whose proportion of the total data variance explained by each successive component is the maximum. Some ecologists have criticized PCA on ecological grounds because it may misrepresent relationships between variables (Gauch and Whittaker, 1977). This problem appears to be minimal with the data set at hand as it involved a narrow range of environment and thus low β-diversity (cf. Shaukat and Uddin, 1989). The efficiency of PCA is reported to increase with decrease in beta diversity (Digby and Kempton, 1987). The eigenvalues for three components were 5.492, 2.493 and 2.091 that accounted for 39.2, 17.80, and 15.0% of variance **(Table 2)** (cumulatively 72% total variance), respectively. Such high figures for variance being defined by the components reflect that non-linear responses of variables to a multitude of other variables are non-existent in data and consequently distortion in the multidimensional relationship of variables due to non - linearities is lacking or is not substantial.

Table 1. Summary of relative phytosociological data.

Species *	Importance Value Index			No. of	Halo-	Dominants		
	Min	Mean	Max	Occurrences	Physiotypes	I	II	III
1. *Salvadora persica*	4.58	71.38	204.02	5	L	1	2	-
2. *Suaeda monoica*	4.95	131.76	267.50	7	L	3	2	-
3. *Salvadora oleiodes*	3.41	3.41	3.41	1	L	-	-	-
4. *Suaeda fruticosa*	9.96	40.79	113.32	6	L	-	3	1
5. *Tamarix indica*	6.90	127.13	269.38	9	X	5	2	1
6. *Cressa cretica*	249.20	274.60	300.00	2	X	2	-	-
7. *Prosopis glandulosa*	7.30	17.50	23.12	3	P	-	1	1
8. *Prosopis juliflora*	35.90	35.90	35.90	1	P	-	-	1
9. *Aeluropus lagopoides*	50.80	50.80	50.80	1	X	-	1	-
10. *Aerva pseudotomentosa*	6.16	6.16	6.16	1	P	-	-	-
11. *Alhagi maurorum*	21.73	21.73	21.73	1	P	-	-	1
12. *Suaeda vermiculata*	217.54	217.54	217.54	1	L	1	-	-

Halophysiotypes (Breckle (1986): L, Leaf succulents ; X, recretophytes; P, pseudohalophytes.

*, Other species not encountered in sampling but recorded (letter in parenthesis shows physiotypes): *Cyperus bulbosus* (P), *Cyperus rotundus* (P), *Desmostachya bipinnata* (X), *Launaea nudicaulis* (P), and *Zygophyllum simplex* (L). A few populations of *D. bipinnata* were seen but they were either very small or highly disturbed due to cutting or grazing.

Table 2. Results of PCA, eigenvalues and eigen vector coefficients together with associated edaphic variables.

Component	Eigenvalues	Variance (%)	Cumulative Variance (%)	Eigen vector Coefficients *	Associated Soil Variable
I	5.492	39.2	39.2	0.410	EC
				0.4.3	Cl
				0.375	Na
				0.335	Sand
				0.307	SAR
II	2.493	17.8	57.2	0.483	P
				0.432	Silt
				0.417	K
				0.352	Ca + Mg
				0.339	SP
III	2.091	14.90	72.0	0.616	Sulphate
				0.411	pH
				0.353	SAR
				0.281	Ca + Mg
				0.244	P

*, First five ranked.

Table 3. Pearson product moment correlation coefficients among various edaphic variables averaged for 0-60 cm depth.

	Sand												
Silt	-0.485	Silt											
Clay	-0.810	+0.186	Clay										
SP	-0.242	+0.250	+0.347	SP									
pH	-0.185	-0.151	+0.240	+0.005	pH								
EC	+0.437	-0.380	-0.678	-0.410	-0.363	EC							
Na	+0.552	-0.437	-0.698	-0.514	-0.265	+0.948	Na						
Ca + Mg	+0.137	-0.139	-0.479	-0.188	-0.499	+0.851	+0.648	Ca + Mg					
SAR	+0.687	-0.419	-0.660	-0.440	-0.016	+0.669	+0.862	+0.198	SAR				
K	+0.396	+0.218	-0.458	-0.279	-0.002	+0.127	+0.215	-0.026	+0.355	K			
HCO_3	+0.273	-0.277	-0.510	-0.426	+0.051	+0.554	+0.470	+0.565	+0.245	+0.087	HCO_3		
SO_4	+0.504	+0.059	-0.451	-0.147	+0.210	+0.157	+0.337	-0.178	+0.623	+0.282	+0.024	SO_4	
Cl	+0.300	-0.341	-0.575	-0.405	-0.452	+0.952	+0.847	+0.918	+0.479	+0.086	+0.601	-0.128	Cl
P	+0.161	-0.601	+0.003	-0.061	0.059	+0.262	+0.261	+0.161	+0.162	-0.272	+0.407	-0.239	0+0.318P

$r_p < 0.05 = 0.576$.

a) Nature of edaphic gradients:

Ordination SUs in the framework of environmental ordination distributed continuously. Primary axis was chiefly the function of *C. cretica* and *S. monoica* -dominated sites and secondary and tertiary axes were controlled by *T. indica* and *C. cretica* dominated sites. The left section of the ordination contained the sites dominated by *C. cretica* and *T. indica* and right side contained the sites dominated by *S. vermiculata*, *S. monoica* and *S. persica* **(Fig. 2).**

The first principal component appeared to be the function of EC, Na+, Cl^-, SAR and soil textural attributes. The second component was controlled by Phosphorus, silt, Potassium, etc. and the third component was governed by sulphate and pH, etc. Component I correlated negatively with clay fraction and positively with EC, Na^+, Ca^{++} + Mg^{++}, Cl^- and SAR. Component II exhibited negative correlation with silt and available P. pH exhibited positive correlation somewhat poorly. Component III showed positive correlation with sulphate and SAR.

Table 4. Results of PCA, eigenvalues and eigen vector coefficients together with associated edaphic variables for five halophytic community types, on the basis of average edaphic characteristics.

Component	Eigenvalues	Variance (%)	Cumulative Variance (%)	Eigen vector Coefficients *	Associated Soil Variable
I	7.720	55.10	55.10	0.358	EC
				0.352	Cl
				0.343	Na
				0.330	Clay
				0.316	SAR
II	3.238	23.10	78.30	0.548	P
				0.470	Silt
				0.471	SP
				0.344	K
				0.279	SO_4
III	2.091	17.90	96.10	0.551	HCO3
				0.506	SO4
				0.364	K
				0.309	Ca + Mg
				0.280	SAR

*, First five ranked.

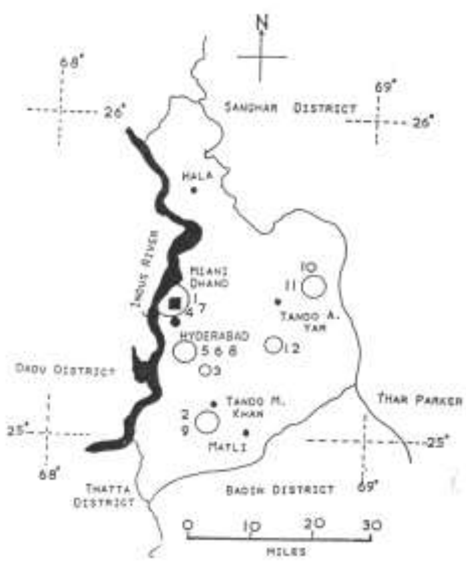

Fig.1. Map of Hyderabad district showing the location of highly saline waterlogged sites studied.

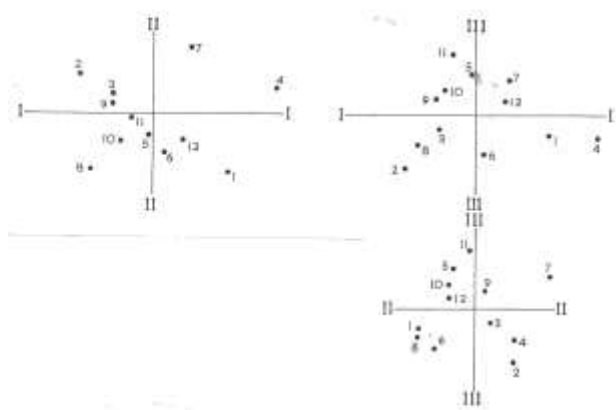

Fig.2. Principal component ordination of 12 highly saline waterlogged Sites of Hyderabad district based on the edaphic conditions (av. Soil variables for 0-60 cm soil depth.

b) Broader groups of the edaphic variables:

Correlations among the edaphic variables are shown in **Table 3.** Available P and K^+ were not correlated with any other factors and sulphate correlated with SAR only. Similarly bicarbonate was correlated to none of the factors except chlorine at $p < 0.05$. Sand and clay fraction of soil, as may be expected, related inversely. EC showed significant positive correlations with Na^+, $Ca^{++} + Mg^{++}$, Cl^- and SAR. The negative correlation between EC and clay content of soil may probably be attributable to gradual decline of EC and increase in the clay fraction with the soil depth. These results indicate that the important environmental factors affecting vegetation in hand can be divided into six broader groups of variables: **1**) Soil textural group (composed of sand, silt and clay), **2**) Salinity and Sodicity (composed by EC, Na, Cl^-, Ca^{++} + Mg^{++}, SAR, etc.) **3**) Bicarbonate level, **4**) Sulphate, **5**) Phosphorus content and **6**) pH.

The upper and lower extreme values of the edaphic variables, averaged for soil depth from 0 to 60 cm, were Clay (0 - 46 %), EC (10.93 - 82.3 dS/m), pH (7.25 - 8.50), HCO_3^- (2.08 - 5.82 meq/l), SO_4^{--}(12.08 - 205.21 meq/l) and P (5.60 - 12.33 ppm). These ranges may roughly provide some idea with respect to the extremes of the derived gradients. In view of the range of salinity encountered, the primary gradient of salinity, for the sake of convenience, may arbitrarily be divided into three levels: **High salinity intensity level- I** (EC: 15 -30 $dS.m^{-1}$), **High salinity intensity level II**- (EC: 30 - 50 $dS.m^{-1}$) and **High salinity intensity level-III** (EC > 50 $dS.m^{-1}$).

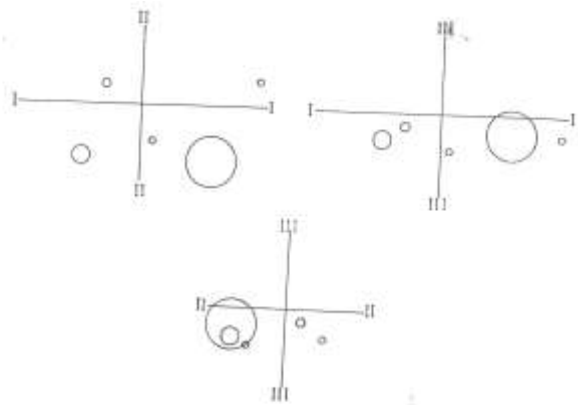

Fig.3. Distribution pattern of *Cressa cretica* in the framework of XY, XZ and YZ (PC I-PC II, PC I-PC III and PC II-PC III) planes of the environmental PCA. Larger is the circle size, larger is the phytosociological conspicuousness of the species.

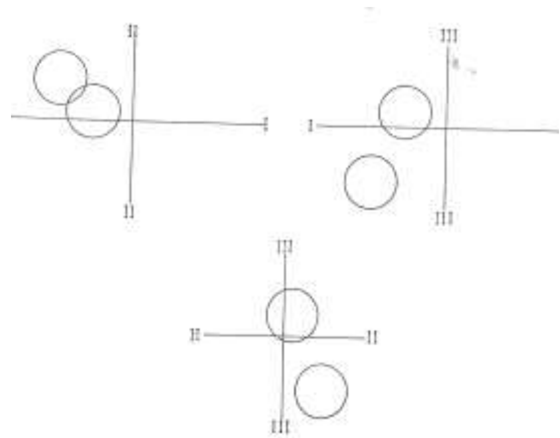

Fig.4. Distribution pattern of *Tamarix indica* in the framework of XY, XZ and YZ (PC I-PC II, PC I-PC III and PC II-PC III) planes of the environmental PCA, Larger is the circle size, larger is the phytosociological conspicuousness of the species.

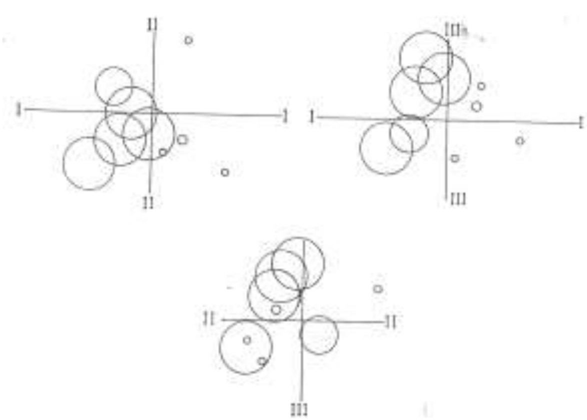

Fig.5. Distribution pattern of *Salvadora persica* in the framework of XY, XZ and YZ (PC I-PC II, PC I-PC III and PC II-PC III) planes of the environmental PCA. Larger is the circle size, larger is the phytosociological conspicuousness of the species.

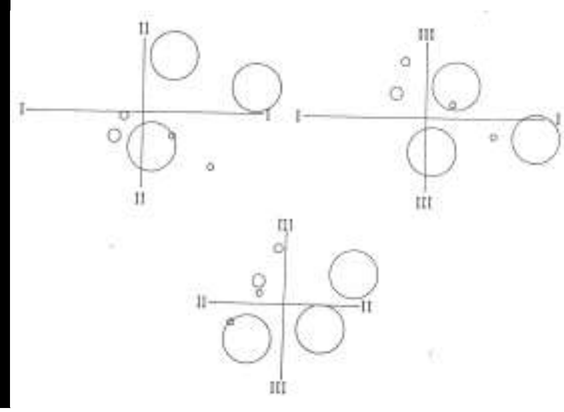

Fig.6. Distribution pattern of *Suaeda monoica* in the framework of XY, XZ and YZ (PC I-PC II, PC I-PC III and PC II-PC III) planes of the environmental PCA, Larger is the circle size, larger is the phytosociological conspicuousness of the species.

c) Behaviour of species along the edaphic gradients:

The behaviour of species along the primary, secondary and tertiary gradients as defined by PCA **(Fig. 3- 7)** may be described as follows:

C. cretica exhibited its greatest activity (dominance) in sites of high salinity intensity level-I with high to moderate clay, low to moderate sulphate, silt and available P **(Fig. 3)**. *T. indica* dominated in the region of high salinity intensity level -II with high to moderate clay content, variable amount of sulphate and low to moderately available phosphorus **(Fig. 4)**. *Salvadora persica* showed its association with high salinity intensity level-III with low clay content, moderate sulphate and low phosphorus availability **(Fig. 5)**. *Suaeda monoica* exhibited its dominance in high salinity intensity level-II and -III with low to moderate clay and sulphate contents and varying magnitude of available phosphorus **(Fig. 6)**. *S. fruticosa* distributed with some prominence in soil of high salinity intensity level -II which is moderately fine -textured and contained moderate to high concentration of sulphate and low to moderate concentration of phosphorus **(Fig. 7)**.

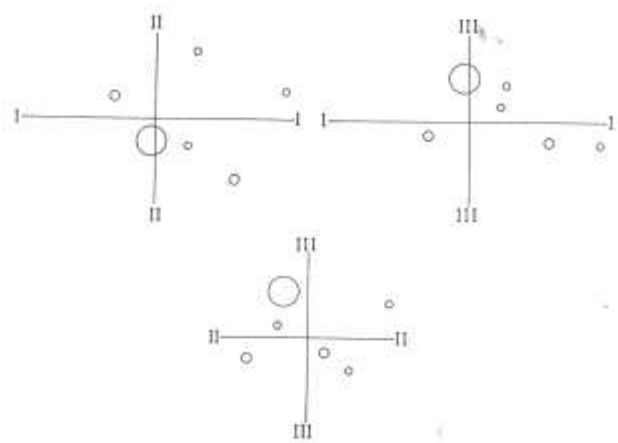

Fig.7. Distribution pattern of Suaeda fruticosa in the framework of XY, XZ and YZ (PC I-PC II, PC I-PC III and PC II-PC III) planes of the environmental PCA. Larger is the circle size, larger is the phytosociological conspicuousness of the species.

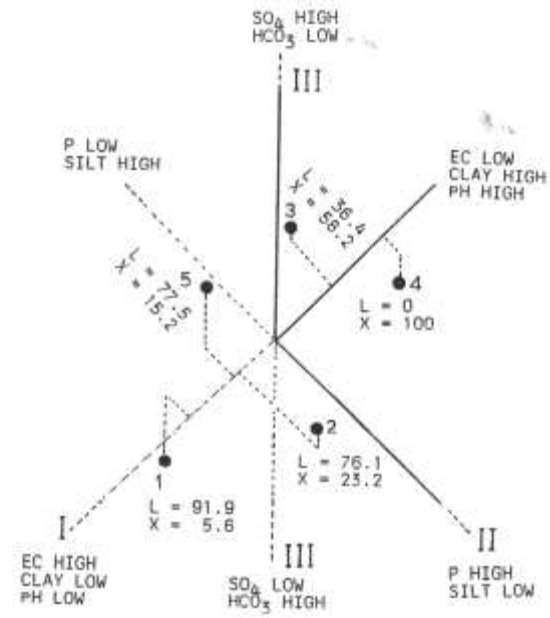

Fig.8. Three dimensional environmental PCA for five vegatational groupings of highly saline and waterlogged soils based on average soil characteristics for 0-60 cm Soil depth.
1: S. persica grouping; 2: S. monoica grouping;
3: T. indica grouping; 4: C. cretica grouping;
5: S. vermiculata grouping, L:leaf succulents,
X: Recretohalophytes.

d) Vegetational Projection along the PCA-derived edaphic gradients:

Cluster analysis of the vegetation data of the SUs, being reported here, were discretely delineated into five community types by Khan *et al*. (2003). In order to arrange these five community types along the derived edaphic gradients, a Q - type PCA was also performed using average edaphic data pertaining to these community types. The results of such an analysis are given in **Table 4** and **Fig. 8.** The eigenvalues for first three components were 7.720, 3.258 and 2.501, which accounted for 55.1, 23.1, and 17.90% of the total variance in data, respectively (cumulative % variance = 96.10). Primary axis appeared to be the function of EC and its associated variables and clay fraction of soil, secondary axis appeared to be governed by P and silt fraction of soil and the tertiary axis correlated with bicarbonates and Sulphate contents of soil.

The communities distributed continuously in three dimensional plane of the ordination **(Fig. 8).** The first principal component was the function of *S. persica* and *C. cretica* communities whereas *T. indica* and *S. monoica* communities governed secondary component and *S. persica* and *S. vermiculata* communities defined the third component. These community types were effectively and principally delineated by salinity intensity level, pH and textural peculiarities of the soil on primary axis, by available P and silt concentration on the secondary axis and sulphate and bicarbonates contents on tertiary axis. The greater competitiveness of leaf succulent halo-physiotypes over recretohalophytes was evident **(Fig. 8)** as the conspicuousness of leaf succulents, in terms of % IVI, increased with salinity and they were predominant in high salinity intensity level-III whereas the conspicuousness of recretohalophytes decreased with salinity and they predominated in high salinity intensity level-I. In the middle of the primary gradient both physiotypes were differentially successful. Such a pattern of competitiveness of L and X types of physiotypes in salinized habitats is in accordance with Breckle (1986) for the halophytic vegetation of Iran and Afghanistan. These two physiotypes were reported to be more or less equally competitive (L = X) in some coastal salt marshes of Pakistan largely due to the abundance of strong recretohalophytes namely *Urochondra setulosa* and *Halopyrum mucronatum* (Khan and Ahmad (1992).

The plexus diagram, prepared on the basis of euclidean distances between the communities, as determined by the formula:

$$d= \sqrt{(x_1-x_2)^2+(y_1-y_2)^2+ (z_1-z_2)^2},$$

Where x, y and z are the values of the environmental principal components associated with the communities, is given in **Fig. 9**. Edaphologically, *T. indica* and *C. cretica* vegetational types are the most similar ones and *S. persica* and *C. cretica* types are the most dissimilar ones. Phytosociologically, *C. cretica* community is absolutely discrete pioneer seral community whereas *S. persica* and *T. indica* dominated communities represent highly evolutive stage of vegetation in moist-saline habitat of Pakistan (Khan *et. al.* 1994). *S. persica* and *T. indica* communities exhibited around 24% IVI-based compositional similarity, which was the highest amongst the communities in hand.

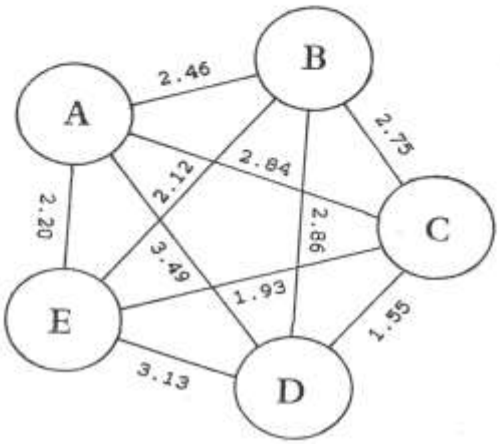

Fig.9. Plexus diagram constructed on the basis of Euclidean distances (ED) between the group centriods. EDs calculated using first three principal components. A: S. Persica grouping; B: S. Monoica grouping; C: T. Indica grouping; D: C. Cretica grouping; E: S. Vermiculata grouping.

The results of our studies indicated that there is specific relationship between soil characteristics and the separation of the vegetation types. Soil salinity, its texture and chemical characteristics are the main factors controlling species distribution which is supported with the studies of Bernaldez *et al* (1989), Caballero *et al.* (1994), Mashaly *et al.* (2001) and Jafri *et al.* (2003) with respect to the edaphic relations of halophytic vegetation. Environmental gradient analysis substantially contributed to the elucidation of underlying causes of plant distribution, however, cause and effect relations at finer levels of plant distribution are difficult to establish through field observations because plant to plant interaction, animal browsing and grazing, cutting, etc. The cause of finer patterns can only be determined through experimentation (Mueller-Dombois and Ellenberg, 1974). There always remains the probability that some of the environmental measurements do not reflect conditions actually experienced by the plants (Bradfield and Scagel, 1984). The individual factors do not act on plants independently but holistically in form of environmental complex.

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