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CCA application for vegetation - environment relationships evaluation in arid environments (southern Khorasan rangelands)

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Abstract

This paper presents a quantitative account of vegetation–environmental factor relationships in arid rangelands. Vegetation cover was recorded using Braun-Blanquet combined abundance-cover scale in each quadrat. Within each quadrat, one profile was dug and soil samples being taken at 0-20cm and 20-100cm depths. Under study physical-chemical characteristics included texture, lime, organic matter, soil moisture content, saturation moisture, EC and pH. Five vegetation groups were identified after the application of Two Way Indicator Species Analysis (TWINSPAN) and Detrended Correspondence Analysis (DCA) methods including: A*: Salsola richteri-Aelorupes littoralis*; B: *Zygophyllum eurypterum-Haloxylon ammodendron*; C: *Artemisia sieberi-Zygophyllum eurypterum*; D: *Ammodendron persicum-Stipagrostis pennata*; E: *Artemisia aucheri-Amygdalus scoparia.* Canonical Correspondence Analysis (CCA) was used in a direct gradient analysis of the vegetation with the environmental variables. The results of CCA showed that first axis represented a landscape and edaphic gradient; it was positively correlated to soil texture and soil saturation moisture; it was negatively correlated with elevation and slope. The second axis represented mainly a soil moisture-salinity gradient; it was positively correlated with EC and soil moisture content. The results showed that those environmental factors that affect water availability were the most effective environmental factors in the distribution of vegetation groups in arid rangelands.

Keywords: Vegetation-environment relationships; Classification; Ordination; CCA; Aridlands

1. Introduction

The relationships between vegetation and environment are an important topic in community ecology (Leng *et al*., 2006). Where a large number of environmental factors are correlated as a result of an overriding influence, it is often difficult to determine which factors are actually causing vegetation patterns (Partridge and Wilson, 1989). Quantitative analysis of ecological relationships between vegetation and the environment has become an essential means in the field of research of modern vegetation ecology (Zhang *et al*., 2006). Quantitative analysis, especially quantitative classification methods and ordination techniques, has been widely used to indicate the ecological relationships between vegetation and the environment (Jiang, 1994). The objective of classification is to group together a set of observational units on the basis of their common attributes (Kent and Coker 1992). Plant communities are complex assemblages of species filtered by the environment from the species pool available after historical and

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chance events (Sebasti, 2004). Using classification, one can evaluate the importance of the assignment of abundance coefficients to vegetation composition. Classification is also of importance to cluster quadrats of high similarity. These clusters are key factors that are related to abiotic variables. It is therefore possible to analyze floristic structures by a hierarchical classification. One of the most popular hierarchical divisive clustering techniques in community ecology is the Two-way Indicator Species Analysis (TWINSPAN) (Zhang and Oxley, 1994). TWINSPAN (Hill, 1979) simultaneously classifies species and samples. Ordination is a collective term for multivariate techniques which adapt a multi-dimensional swarm of data points in such a way that when it is projected onto a two dimensional space any intrinsic pattern the data may possess becomes apparent upon visual inspection (Pielou, 1984). The ordination techniques proved to be a useful tool in the elucidation of the cluster pattern as well as in the detection of the main environmental variation underlying the floristic variation within the data (Mucino, 1982). Canonical correspondence analysis (CCA) is introduced as a multivariate extension of weighted averaging ordination, which is a simple method for arranging species along environmental variables (ter Braak, 1987).

Desertification processes have and continue to be of major concern for management of this region. In order to control desertification and to better manage rangeland ecosystems of the aridland, evaluation of relationships between vegetation and environmental factors in this region is important.

The first aim of this study was to define the vegetation groups, using TWINSPAN technique. The second aim of this study was to analyze the distribution patterns of vegetation groups and the relationships between the vegetation groups and environmental factors, using DCA and CCA techniques.

2. Study area

The study area (144000 ha) is located to the northeast of South Khorasan province, at 33° 15′- 33° 45′ N and 59° 45′- 66° 00′ E. It is part of the Eastern Watershed of Iran. The maximum elevation of the region is 2730 m on Shaskouh Mountain and the minimum elevation is 530 m in the Petergan Playa. Average annual temperature range from 8.81 to 26.87°c. Average annual precipitation of study area range from 105.16 to 271 mm. Rainfall is not only low but also falls in short periods interspersed with long dry periods. Climate is arid, according to Demartonn method. The study area comprises sand dunes and alluvial deposits. Soils are predominantly regosols, andoslos, lithosols and alluvial. In view point of phytogeography, this area belongs to zone of Irano – Turanian region, Western Asiatic subregion, Aremeno – Iranian province, Khorasan subprovince (Rostampour, 2008). Meteorological data such as average annual precipitation and temperature were calculated for a ten-year period.

3. Materials and methods

3.1. Vegetation sampling and analysis

A vegetation analysis of Zirkouh rangelands was carried out during 2007, when most of species were expected to be growing. Sampling quadrats were established at 7 sites, selected from typical vegetation types in the region. Vegetation types were identified based on field surveys. A total of 181 quadrats were sampled with randomized - systematic method. At each site four parallel transect each of 150m long were laid out at 100-m intervals and 6-8 quadrats of 2-16 m^2 were located along it. The Braun Blanquet method was used in estimating canopy cover percentage and frequently using the 7-division scale (Westhoff & Van Der Maarel 1978). Density was determined by delimiting and counting individuals of each species. The similarity of species composition, described by the Sørensen index, between each pair of the sites, was calculated. The Sørensen index was calculated as:

$$IS_c = \frac{2C}{A+B} \quad (1)$$

Where C is the number of species shared in both sites, A the species occurring only in site A and B the species occurring only in site B (Asri, 1995). Species were identified in the field and samples of unknown species were collected and identified in the herbarium of Natural Recourses Faculty in University of Tehran. Field data included a through description of environmental factors of the sampled site such as quadrates location, altitude, slope gradient and aspect. Those were determined in the field using a GPS, altimeter, clinometer and compass, respectively.

3.2. Soil analysis

Soil analysis was conducted during Juan and July. Two soil samples were taken from each quadrat to two depths of 20cm and 100cm. The physical and chemical properties of the soil, particularly in the rooting zone, which for most vascular plants is to a depth of 20 cm or so, plays a very important role in shaping vegetation (see Solon et al., 2007). Samples were thoroughly mixed, air-dried and sieved to pass a 2mm sieve to remove rocks, gravel and debris. Then one subsample was taken, which was labeled and kept in a plastic bag for analysis. The fine earth fraction was retained for chemical analysis. Soil samples were analyzed for soil moisture content (SM), saturation moisture percentage (SP), texture, pH, electrical conductivity (EC), $CaCo_3$ and organic matter (OM). Percentage moisture content was calculated as the difference between the pre- and post-drying weight divided by the pre-drying weight. Soil texture was determined by the Bouyoucous hydrometer method (Bouyoucous, 1962), and the result used to calculate the percentages of sand, silt and clay. Soil pH was measured in soil extract (soil water ratio = 1:5) and electrical conductivity (EC) was measured using a conductivity meter. $CaCo_3$ percentage determined using 1N HCl, and organic matter content estimated by the Walkley and Black method (1934). The soil analyses were conducted at Soil Testing Laboratory of Natural Recourses Faculty in University of Tehran.

3.3. Statistical analysis

The 181 Quadra vegetation data from Zirkouh rangelands was analyzed using the multivariate analysis methods. Data analysis was performed on the abundance – cover scale all quadrats per site. The data were entered into a Microsoft Excel spreadsheet then transferred to the PC-ORD program (McCune and Mefford, 1999). Species with less than 2 entries were deleted to increase the definition of the results (Baruch, 2005). The resulting samples-by-species data matrix consisted of 44 species and 181 quadrats. The floristic data were classified with TWINSPAN technique (Hill, 1979). TWINSPAN is a numerical method of polythetic divisive classification (Mesdaghi, 2005). From TWINSPAN, an ordered two-way table, which expressed succinctly the relationships of the samples and species within the set data, was constructed (He *et al*., 2007).

An indirect gradient analysis, the Detrended Correspondence Analysis (DCA, Hill, 1979; Hill and Gauch, 1980) was applied for preliminary analysis of species data. DCA was used to determine lengths of the gradients (Eilertsen *et al*. 1990). This is an indirect ordination technique that provides a description of changes in the vegetation along the environmental gradients (Hill and Gauch, 1980). The length of the gradient from the first analysis serves as a lead for selecting between CCA and RDA (Lepš and Šmilauer, 1999). Gradients were sufficiently long (> 2 SD) to justify use of CCA, which assumes species have a unimodal response to the environmental gradients (ter Braak 1995). The relationship between plant species variation and environmental variation was assessed using canonical correspondence analysis (CCA) (Ter Braak, 1986). For this analysis, a second samples-by environmental factors data matrix was also constructed; it consisted of 14 environmental factors and 181 quadrats. In this analysis species scores were weighted averages of eigenvector sample scores and biplot scores of environmental variables were correlations with the ordination axes. The importance of each CCA axis is represented by the eigenvalue, which measures how much variation in the species data is explained by the combination of environmental variables for the axis (ter Braak 1995). Intra-set correlations from the CCAs are therefore used to assess the importance of the environmental variables (Abd El-Gani and Amer, 2003). Statistically significant environmental factors tested by the Monte Carlo permutation test were used in analyses (ter Braak and Smilauer, 1998). Permutation tests were run with 999 permutations. For the gradient analysis the computer program CANOCO version 4 (ter Braak and Smilauer 1998) was used. Ordination diagrams were drawn in CanoDraw 3.1 (Smilauer, 1997). For each of the vegetation groups, the mean and standard deviations were calculated for the environmental parameters. The variation in the environmental variables in relation to vegetation groups were tested using one-way analysis of variance (ANOVA) procedure of SPSS version 12.0.1 for windows (Julie, 2001). Duncan's multiple range test was used for mean separation when the analysis of variance showed statistically significant differences ($p<0.05$). Soil parameters were checked for normality with the Kolmogorov-Smirnov test.

4. Results

4.1. Classification

Using TWINSPAN, the rangeland communities were classified into five groups. In this analysis, 181 quadrats were classified into five groups (Figure. 1 a). Each vegetation group was named based on dominant or indicator species. Subsequent to the classification of vegetation groups a synoptic table was prepared from the output of TWINSPAN (Table 1). The most number of plant species (22) is related to vegetation group D and the least of it (7) is related to vegetation group A (Table 1).

In the first division, 181 quadrats have divided to two clusters that in left direction exists 28 quadrats with *Artemisia aucheri* and *Amygdalus scoparia* indicator species (Group E). In right direction exists 153 quadrats and exists no indicator species. The second division 153 quadrats have divide to two clusters that in right direction exist 80 quadrats with *Ammodendron persicum* and *Stipagrostis pennata* indicator species (Group D) and left direction exists 73 quadrats and exists no indicator species. In third division, 73 quadrats divided to two clusters that in left direction exists 25 species with *Salsola richteri* and *Aelorupes littoralis* indicator species (Group A). In right direction exists 48 quadrats and exists no indicator species. The forth division, 48 quadrats have divided to two clusters that in left direction exists 25 species with *Zygophyllum eurypterum* and *Haloxylon ammodendron* indicator species (Group B) and right direction exists 23 quadrats with *Artemisia sieberi* and *Zygophyllum eurypterum* indicator species (Group C). These groups were subsequently compared with the groups identified in the DCA method. Appendix includes the complete list of the plant species used in Figure 1 (b). The resulting DCA diagram provided a visual summary of the species composition data from the sample plots. The TWINSPAN groups were drawn in by hand on the DCA diagram (Figure 1 b).

There was a certain degree of overlap among B, C and D vegetation groups. Sørensen index (IS_s) between the five vegetation groups was shown in Table 2. Between groups B, C and D there are significant relations, but groups A and E have the lowest similarities with other groups.

A brief description of each group is coming as follows:

A: *Salsola richteri - Aelorupes littoralis* group.This group was founded in highly saline and humid soils and low places. The altitude varied from 550 masl to 580masl. The mean precipitation of this group is the lowest of all the groups (105mm) and the mean temperature the highest (26 C°). This group was found in the places with the highest content of Clay, Organic matter, EC, Saturation moisture and Soil moisture content.

B: *Zygophyllum eurypterum - Haloxylon ammodendron* group. This group was founded between 800 and 970masl. The mean precipitation was 125mm.This group founded in places where covered by trees and shrubs. Group

C: *Artemisia sieberi - Haloxylon ammodendron* group. This group was founded between 900 and 1020masl. The mean precipitation was 136mm. This group is the same of group B, according to soil and topography properties.

D: *Ammodendron persicum - Stipagrostis pennata* group. This group was founded in sand duns. The elevation varied from 900masl to 1200masl. The mean precipitation was 133mm and the mean temperature was 21.8 C^{o}. The content of sand in the soil was the highest compared with the other groups, but Soil moisture content was the lowest of all. This group was covered by shrubs and bunch grasses.

E: *Artemisia aucheri - Amygdalus scoparia* group. This group was founded in high places (1200 to 1670masl). So, the mean precipitation of this group is the highest of all the groups (185mm) and the mean temperature the lowest (13.5 C°). Slope is between 70-80% in this group.

To provide greater insight into the relation between vegetation and the environmental factors, detailed environmental measurements and vegetation groups' descriptions were performed. A summary of environmental factors for each of the five vegetation groups obtained by TWINSPAN in the study area is presented in Tables 3 and 4. Significant differences could bee seen in many of the environmental factors of these groups. Of the measured soil factors only $CaCo_3$ shows no significant differences among the vegetation groups.

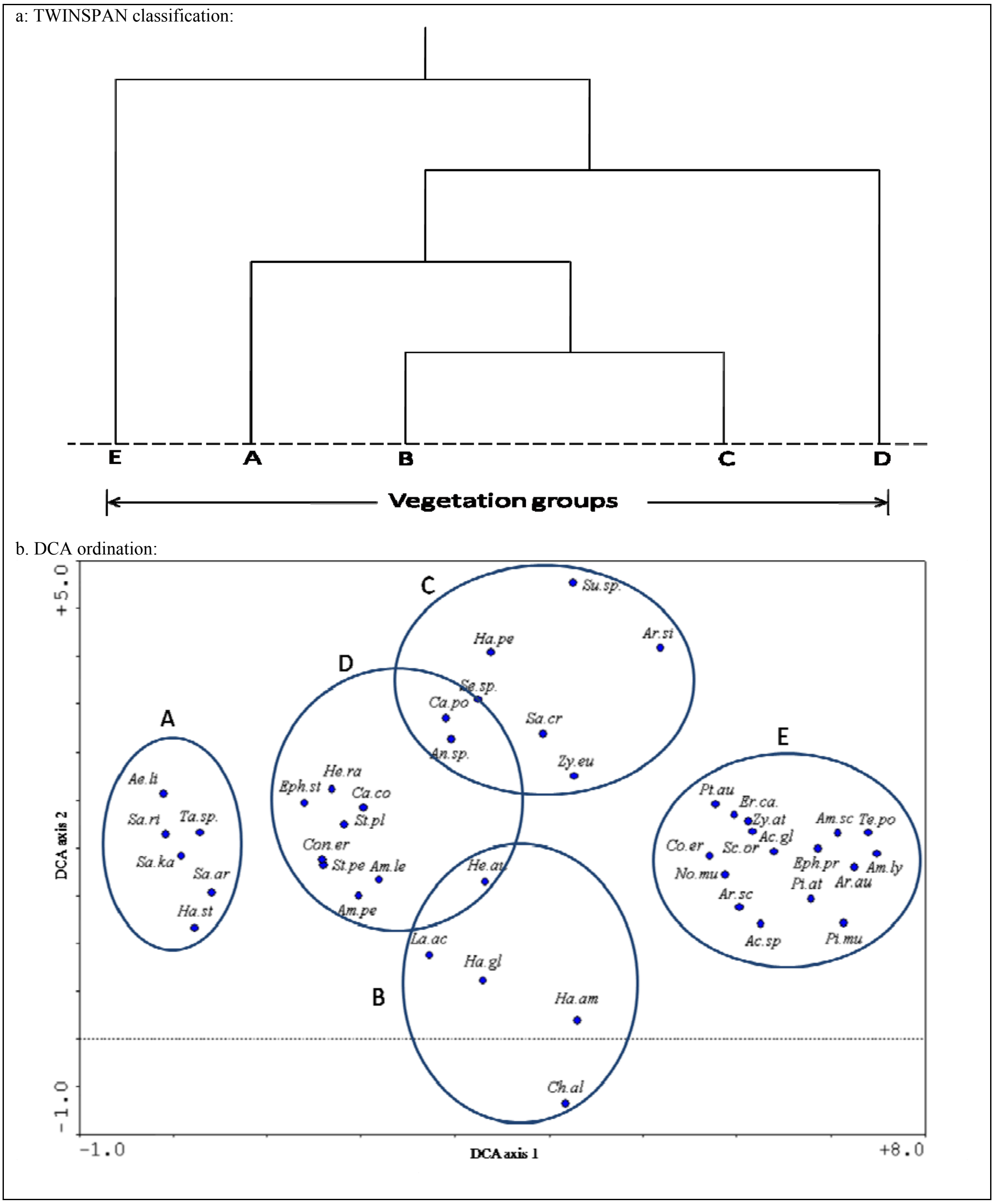

Fig. 1. Relationship between the five vegetation groups obtained after the application of TWINSPAN (a) and DCA (b) techniques. For species abbreviations see Appendix. The five groups are: group A: *Salsola richteri-Aelorupes littoralis*, group B: *Zygophyllum eurypterum-Haloxylon ammodendron*, group C: *Artemisia sieberi-Zygophyllum eurypterum*, group D: *Ammodendron persicum-Stipagrostis pennata*, group E: *Artemisia aucheri-Amygdalus scoparia*.

Table 1. Synoptic table of the indicator and preferential species of the vegetation groups obtained by TWINSPAN in the study area with their presence estimates

Vegetation group	Species				
	A	B	C	D	E
Number of sample plots	28	80	23	25	25
Total number of species	22	20	12	11	7
Salsloa richteri	●	-	-	-	-
Aelorupus littoralis	●	-	-	-	-
Salsloa arbuscula	○	-	-	-	-
Zygophyllum eurypterum	-	●	●	-	-
Haloxylon ammodendron	-	●	○	-	-
Halothamnus glaucus	-	○	-	-	-
Suaeda audiflora	-	○	-	-	-
Andrachen sp.	-	-	○	○	-
Ammodendron persicum	-	-		●	-
Stipagrostis pennata	-	-	-	●	-
Stipagrostis polumosa	-	-	-	○	-
Calligonum comosum	-	-	-	○	-
Ammothamnus lehmannii	-	-	-	○	-
Convolvulus eremophylus	-	-	-	○	-
Heliotropium aucheri	-	-	-	○	-
Artemisia aucheri	-	-	-	-	●
Amygdalus scoparia	-	-	-	-	●
Amygdalus lycioides	-	-	-	-	○
Artemisia sieberi	-	○	○	-	○
Teucriom polium	-	-	-	-	○

●=above 50%, ○=less than 50%, -=absence.

Table 2. Sørensen index (IS_5) between the vegetation groups obtained by TWINSPAN in the study area. *=p≤0.05, **=p≤0.01

Vegetation group	A	B	C	D	E
A	-	-	-	-	-
B	11.11	-	-	-	-
C	10.52	*26.08	-	-	-
D	14.81	**38.70	**43.75	-	-
E	6.89	6.06	17.64	13.63	-

Table 3. Mean ± standard error of the Environmental factors in the vegetation groups obtained by TWINSPAN in the study area

Environmental factors	Vegetation group					F-ratio	P-values
	A	B	C	D	E		
Elevation (m asl)	554±6.43 a	927±41.44 b	1040±112.09 b	1006±56.27 b	1650±85.62 c	7.62	0.01
Slope (%)	1.36±0.43 a	7.90±0.83 a	12.18±1.77 a	30.18±2.07 b	78.3±2.50 c	11.78	0.00
Aspect	S a	SE a	W b	NW c	N c	9.54	0.01
Precipitation (mm)	105.52±0.5 a	127.38±3.32 b	136.4±8.97 b	133.6±4.55 b	185.26±10.3 c	7.47	0.01
Temperature (c°)	26.18± 0.08 a	23.21±0.54 b	20.95± 1.48 b	20.71± 0.74 b	13.67 ±1.30 c	7.62	0.01

$^{a-c}$ Values within rows not followed by same letter differ significantly ($p < 0.05$).

Table 4. Mean ± standard error of the soil factors in the vegetation groups obtained by TWINSPAN in the study area

Soil factors	Vegetation group				F-ratio	P-values
	A	B	C	D		
Sand (%)	57.90±5.68 a	70.40±1.75 b	69.97±2.56 b	87.12±0.78 c	35.46	0.00
Silt (%)	18.20±4.61 a	8.97±3.62 b	10.54±2.35 b	1.55±0.32 c	16.73	0.00
Clay (%)	23.88±1.94 a	20.63±2.55 a	19.47±2.28 a	10.95±0.79 b	17.36	0.00
EC (ds/m)	16.73±1.91 a	1.38±0.78 b	0.26±0.02 b	0.24±0.01 b	125.80	0.00
pH	8.39±0.08 a	8.10±0.13 b	7.95±0.03 b	7.96±0.04 b	8.97	0.00
$CaCo_3$ (%)	11.29±1.30ns	14.22±0.67ns	14.14±0.67ns	13.95±0.32ns	8.39	0.13
Soil moisture content (%)	6.21±1.12 a	2.00±0.33 b	1.55±0.09 b	0.50±0.02 c	34.57	0.00
Saturation moisture (%)	35.91±2.45 a	27.30±1.28 b	28.33±1.07 b	26.33±0.37 b	14.96	0.00
Organic matter (%)	2.72±0.74 a	1.84±0.25 b	1.88±0.16 b	0.89±0.16 b	5.67	0.05

No samples were collected from vegetation group E due to rockiness of site. $^{a-c}$ Values within rows not followed by same letter differ significantly ($p < 0.05$).

4.2. Ordination

The relationship between plant species variation and environmental variation was assessed using canonical correspondence analysis (CCA). The cumulative percentage variances of species-environment relation for axes of CCA (and their eigenvalues) are: 40.90 (0.65) and 65.30 (0.38) for axes 1 and 2, respectively. The species-environment correlations calculated for by the first two axes of CCA are: 0.85 and 0.90 (Table 5). A Monte Carlo permutation test (Table 6) showed that the vegetation - environment relationships revealed by axis 1 and all axes were significant (p = 0.01).

Table 5. Eigenvalues and Species-environment correlations of the first two CCA axes

	Axis 1	Axis 2
Lengths of gradient (checked by DCA)	7.28	4.05
Eigenvalues	0.65	0.38
Species-environment correlations	0.85	0.90
Cumulative percentage variance of species data	19.10	30.30
Cumulative percentage variance of species-environment relation	40.90	65.30

Table 6. Monte Carlo permutation test (99 permutations)

	Eigenvalues	F-ratio	P-value
First canonical axis	0.65	5.18	0.01
All canonical axes	1.58	1.47	0.01

Correlations between the first two CCA axes and environmental factors were determined. The strongest correlations with the first CCA axis were for soil saturation moisture, soil texture, Slope and elevation. The second CCA axis was highly correlated with EC and soil moisture content (Table 7).

Table 7. Intra-set correlations of environmental factors with the first two CCA axes

Environmental factors	Axis 1	Axis 2
Elevation (masl)	-0.57	-0.40
Slope (%)	-0.85	-0.02
Aspect	-0.09	0-11
Precipitation (mm)	-0.19	-0.39
Temperature (c°)	0.19	0.39
Sand (%)	0.95	-0.21
Silt (%)	0.45	0.30
Clay (%)	0.62	0.21
EC (ds/m)	0.41	0.87
pH	0.31	-0.05
CaCo3 (%)	0.30	-0.07
Soil moisture content (%)	0.46	0.72
Saturation moisture (%)	0.95	0.06
Organic matter (%)	0.22	0.31

Values in bold indicate correlations > ±0.50

The CCA species - environment biplot of the first two axes (Fig. 2) shows that each vegetation groups reflects the ecological relationships between vegetation groups and their environments. The first CCA axis represents a landscape gradient, that is, the elevation, slope and sand increase from left to right along the first axis. The second axis clearly reflects a soil moisture-salinity gradient, that is, EC and soil moisture content gradually declines from the top to the bottom along the second axis. Group A, which appeared at low elevations and on saline and moisture soil, is located at top of the second axis and its environment is relatively warm and humid. Group B and group C which occurred at clayey and calcareous soil and are usually present at the middle elevation, are under group A. Group D which occurred at sandy soil is situated on the bottom the second axis. Group E, which occurred at high elevations and steep slopes, is placed in the right direction of the first axis and its environment is characterized by cold. The distribution of this group is influenced by elevation and aspect.

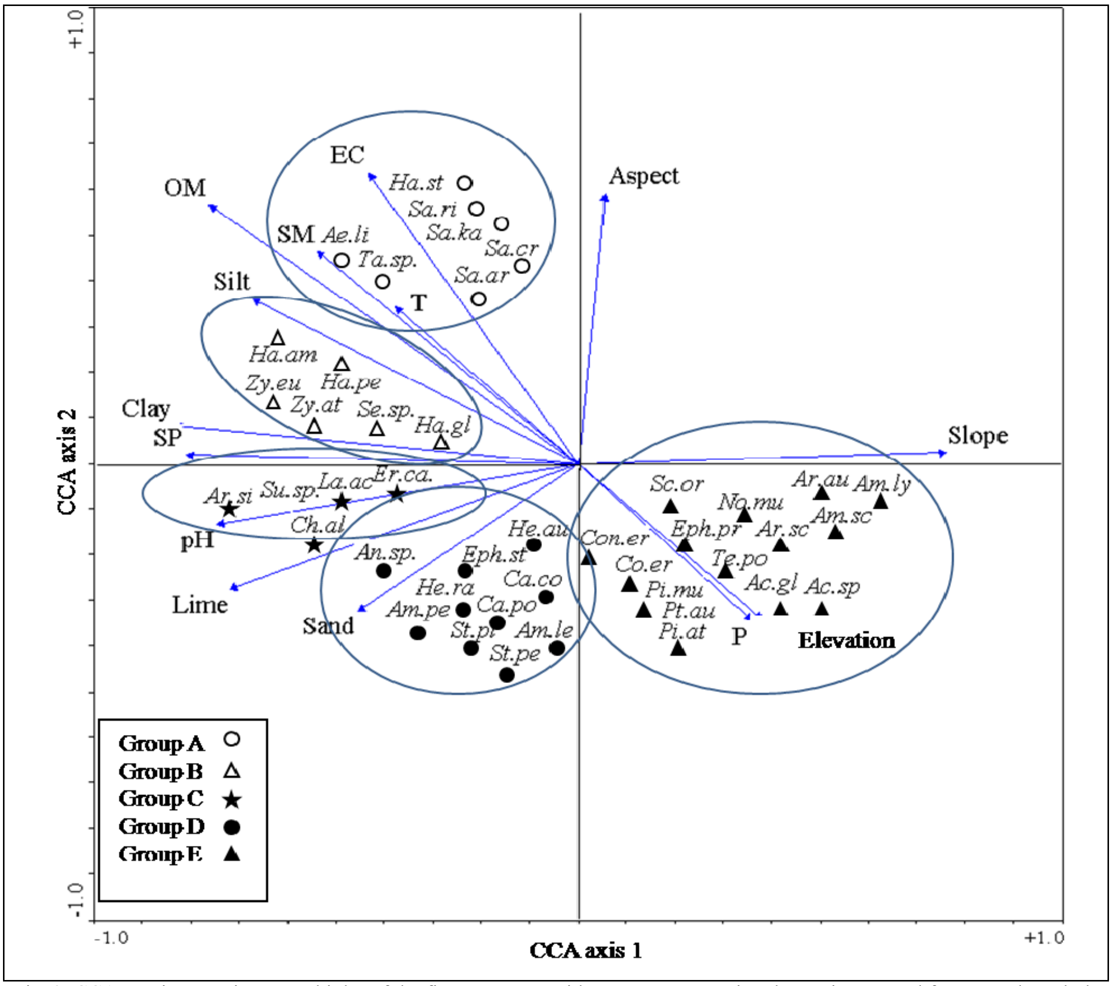

Fig. 2. CCA species - environment biplot of the first two axes, with arrows representing the environmental factors and symbols indicating the 43 species. For species abbreviations see Appendix. SP: saturation moisture percentage, SM: soil moisture content, OM: organic matter, P: precipitation and T: temperature. TWINSPAN classification groups are indicated bye different symbols: group A: *Salsola richteri-Aelorupes littoralis* (○), group B: *Zygophyllum eurypterum-Haloxylon ammodendron* (●), group C: *Artemisia sieberi-Zygophyllum eurypterum* (★), group D: *Ammodendron persicum-Stipagrostis pennata* (▲), group E: *Artemisia aucheri-Amygdalus scoparia* (∆).

5. Discussion and conclusion

This paper presents a quantitative account of vegetation-environmental factor relationships in the Zirkouh rangelands of Qaen in Iran, using methods of TWINSPAN, DCA and CCA. 181 collected quadrats were classified into five vegetation groups by TWINSPAN, and the distribution of the vegetation groups could comprehensively reflect the influence of environmental factors. These groups were ordered along a gradient of topographic relief from depressions with permanent standing water (group A) through flats and sand dunes (groups B, C and D) and mountain (group E). Classification and CCA ordination results were compared. The TWINSPAN groups could be recognized in the CCA graph, too. The ordination graph generated by CCA visualizes not only a pattern of community variation (as in standard ordination) but also the main features of the distributions of species along the environmental factors. Applications demonstrate that CCA can be used both for detecting species-environment relations, and for investigating specific questions about the response of species to environmental variables (ter Braak, 1987). One of the most popular statistical methods in plant ecology at the present time is CCA (Austin, 2002). CCA has the advantage of analyzing simultaneously all the environmental variables potentially determining species habitat selection (Baguette, 1993).

First axis represented a landscape gradient; it was positively correlated to soil texture and soil saturation moisture; it was negatively correlated with elevation and slope.

Soil texture plays an important role in determination of vegetation groups (Ahmadi and *et al*., 2002). Numerous studies have shown the importance of soil texture for vegetation (Abbadi and El Sheikh, 2002 and Davies *et al*., 2007), because soil texture controls dynamics of soil organic matter or organic matter decomposition and formation as well as influences infiltration and moisture retention and the availability of water and nutrients to plants (He *et al*., 2007). Azarnivand *et al.* (2003) concluded that soil texture is one of the most important affective factors in the distribution of *Artemisia sieberi* and *Artemisia aucheri* in Vard Avard, Garmsar and Semnan rangelands of Iran. Soil moisture content has many effects on the distribution of vegetation groups and plant species. The result of this study for magnitude of soil moisture is confirmed by Abd EI-Ghani, 1998 and Mohtasham nia *et al*., 2007. Munhoz *et al.* (2008) found the significant correlations between soil texture and soil moisture features and species distribution. In summary, among different environmental factors, soil is of high importance in plant growth, and is a function of climate, organisms, topography, parent material and time (Hoveizeh, 1997).

Altitude and bare rock percent cover control vegetation patterns on rocky slopes (Vogiatzakis *et al*., 2003). Zhang *et al.* (2006) also showed that altitude is an important factor, because the change of altitude gradient will lead to changes in the temperature and humidity gradients. Davies *et al*. (2007) suggested that slope was the only non-soil factor to be at least moderately correlated with plant species composition in *Artemisia tridentates* alliance. Climate, soil properties and topography are factors that determine plant species distribution (He *et al*., 2007).

The second axis represented mainly a soil moisture-salinity gradient; it was positively correlated with EC and soil moisture content. Abu-Ziada (1980) also notes strong relationships between the vegetation pattern and the soil moisture-salinity gradients in the Kharga and Dakhla Oases (see Abd El-Ghani, 2000). Different sets of soil properties influence the distribution pattern of species and communities (Piernik, 2005). Spatial and temporal heterogeneity of soil variables were related to species distribution (Kwon *et al*., 2007). The study of the spatial patterns in ecology helps to understand the processes that control species distribution (Legender and legender, 1998).

The results showed that the distribution of the vegetation groups was closely related to edaphic and topographic factors. In general, the most important ecological factors influencing vegetation groups in Zirkouh rangelands are soil texture, EC, soil saturation moisture, soil moisture content, slope and elevation. Soil properties and topography are abiotic factors related to water availability (He *et al*., 2007). Soil moisture and texture, altitude and slope are physical environmental variables affecting water availability (Enright *et al*., 2005). The results showed that those environmental factors that affect water availability were the most effective environmental factors in the distribution of vegetation groups in Zirkouh rangelands of Qaen. Similar to our findings, Enright *et al.* (2005) resulted that physical environmental factors likely to affect water availability were more important than soil chemical properties in determining the distribution of the major vegetation types in Krithar National Park, Pakistan.

The interactions of plants with both biotic and abiotic environmental factors are thought to lead to the establishment of structural patterns that reflect community organization (Sebastia, 2004). Understanding relationships between environmental variables and vegetation distribution helps us to apply these finding in management, reclamation, and development of arid and semi arid grassland ecosystems (He *et al*., 2007). Management and restoration of vegetation patterns in arid land ecosystems depends on an understanding of allogenic environmental factors that organize species assemblages and autogenic processes linked to assemblages (King *et al*., 2004). Potential vegetation environments (e.g., habitat types, range sites, ecological sites) are important to land managers because they provide a conceptual basis for the description of resource potentials and ecological integrity (Jensen *et al*., 2001).

Appendix: List of full authorities of plant species abbreviations given in Figures 1 and 2

Acanhtophyllum glandulosum	*Ac. gl*	*Haloxylon persicum*	*Ha. pe*
Acantholimon sp.	*Ac. sp.*	*Halothamnus glaucus*	*Ha.gl*
Aelorupus littoralis	*Ae. li*	*Heliotropium aucheri*	*He.au*
Agriophylum minus	*Ag. mi*	*Heliotropium ramosissimum*	*He. ra*
Ammothamnus lehmannii	*Am. le*	*Heliotropium transoxantum*	*He.tr*
Amygdalus lycioides	*Am. ly*	*Launaea acanthodes*	*La.ac*
Ammodendron persicum	*Am. pe*	*Noaea mucronata*	*No.mu*
Amygdalus scoparia	*Am. sc*	*Pistacia atlantica*	*Pi. at*
Andrachen sp.	*An. sp.*	*Pistacia mutica*	*Pi. mu*
Artemisia aucheri	*Ar. au*	*Pteropyrum aucheri*	*Pt. au*
Artemisia scoparia	*Ar. sc*	*Salsola arbuscula*	*Sa. ar*
Artemisia sieberi	*Ar. si*	*Salsola kali*	*Sa. ka*
Calligonum comosom	*Ca. co*	*Salsola richteri*	*Sa. ri*
Calligonum polygonoides	*Ca. po*	*Salsola tomentosa*	*Sa. to*
Chenopodium album	*Ch. al*	*Scariola orientalis*	*Sc. or*
Convolvulus eremophylus	*Co. er*	*Stipagrostis pennata*	*St. pe*
Cousinia eryngioides	*Co. er*	*Stipagrostis polumosa*	*St. pl*
Eringium capestre	*Er. ca*	*Suaeda audiflora*	*Su. au*
Ephedra procera	*Eph. pr*	*Teucrium polium*	*Te. po*
Ephedra strobilacea	*Eph. st*	*Zygophyllum atriplicoides*	*Zy. at*
Haloxylon ammodendron	*Ha. am*	*Zygophyllum eurypterum*	*Zy. eu*

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