DESERT

DESERT
Online at http://jdesert.ut.ac.ir

DESERT 18 (2013) 19-26

Influence of Environmental Factors on Distribution of Plant Species in Nodushan Rangelands of Yazd Province (Iran)

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Received: 28 August 2011; Received in revised form: 11 February 2013; Accepted: 9 March 2013

Abstract

The purpose of this study was to evaluate the species-environment relationships in arid and semi-arid rangelands of Nodushan, Yazd. The plant species cover and the environmental variables were measured at 9 sites. Soil samples were taken for measurement of 12 attributes in 0-10 cm and 10-80 cm layers. Vegetation was classified using two-way indicator species analysis (TWINSPAN). Data was analyzed using the ordination method of canonical correspondence analysis (CCA). Results showed that soil texture, organic matter, gypsum, salinity, C/N ratio, and elevation greatly affected the distribution of vegetation. *Anabasis aphylla* reflected the high salinity and saturation moisture content of soils. *Ephedra strobilacea* reflected a high level of soil gypsum and a high C/N ratio. *Artemisia aucheri* was characterized by a gradient of increasing elevation, high organic matter, and available water. Determining the vegetation-environment relationships at these sites facilitates the improvement and reclamation of arid and semi-arid shrubland ecosystems.

Keywords: Arid and semi arid rangelands; Nodushan; Ordination; Soil; Species-environment

1. Introduction

The restoration and management of rangeland ecosystems in arid and semi-arid environments will require an understanding of environmental variables that affect plant growth and distribution. One important characteristic of an arid environment is the high intensity of plant and soil variability (Tongway & Ludwig, 1994). The deficiency of precipitation in arid zones results in low vegetation cover. Generally, there is a strong correlation between climate and the distribution pattern of plant species (Austin et al., 1990) and communities (Zhang, 1987) over a wide spatial scale. Soil, one of the important factors affecting distribution and growth of plants, plays an important role in the ecology of vegetation (Muller-Dombois & Ellenberg, 1974). Hejcmanova–Nezerkova and Hejcman (2006) stated that soil type and topography are the main factors affecting woody vegetation. The effects of environmental factors on the distribution of vegetation have been studied in different environmental climates, especially in arid and semi-arid environments. Jafari et al. (2004) suggested that the distribution pattern of vegetation in the Poshtkouh rangelands of Yazd was mainly related to soil characteristics such as salinity, texture, and soluble potassium, gypsum, and lime contents. Zhang et al. (2005) used canonical correspondence analysis to analyze the distribution and floristics of desert plant communities in the lower reaches of the Tarim River in southern Xinijiang, China. Their results indicated the existence of a major

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botanical gradient relating to ground-water depth and the existence of a secondary gradient including soil moisture, pH, and, to a lesser extent, alkalinity and mineralization. Arzanivand et al. (2010) revealed the significant influence of soil texture, EC, SAR, ESP, and pH on *Halecnemum strobilaceum* type and SAR, ESP, and slope in the habitat of *Artemisia sieberi* and *Sedlitzia rosmarinus* types along the southern margin of Haj Aligholi Kavir, Damghan. Tavili et al. (2009) applied CCA for evaluating vegetation-environment relationships in the arid rangelands of southern Khorasan and concluded that environmental factors affecting water availability were the most effective in the distribution of vegetation groups. Identifying environmental variables that influence the distribution of plant species and communities remains a central goal in ecology. The purpose of this study was to identify the environmental factors affecting the distribution of plant species. The determination of such relationships is necessary for the management and reclamation of rangeland ecosystems.

2. Material and Methods

2.1. Study area

The Nodushan rangelands are located in northwestern Yazd in the center of Iran (31°46′N, 52°24′E to 32°15′N, 52°47′E) between the elevations of 1530m to 3260 m. The mean annual precipitation of the study sites ranges from 110 mm to 340 mm. The mean annual temperature is 13°C (Baghestani, 1993). To determine vegetation-environment relationships, 9 sites (vegetation types) were selected in the rangelands of Nodushan. Sites 1 to 8 had an arid climate, and Site 9 had a semi–arid climate. Elevation and slope classes of the study sites are presented in Table 3. The floristic list and cover percentage of the studied plant species are shown in Table 4.

2.2. Data collection and analysis

To determine vegetation-environment relationships, 9 sites (vegetation types) were selected in the Nodushan rangelands. Within each site, four parallel 100m transects were located. The vegetation cover was estimated in 15 equidistantly-located 2×2.5m quadrats along each transect (60 quadrats in each vegetation type). In the middle of each transect, a soil sample was taken between 0-10 cm and 10-80 cm layers (72 samples in 9 vegetation types). Surface soil is important because of its role in shaping vegetation (Solona et al., 2007), the water cycle (e.g., partition of precipitation between surface runoff and infiltration) (Beven and Fisher, 1996), the nutrient cycle (Lehmann et al., 2001), vegetation regeneration (Yamada, 2011), and because it contains the highest concentration of organic matter. Subsoil is important in relation to drainage, water holding capacity, growth of deep rooting plants, and the long term supply of minerals and nutrients. Soil attributes measured include electrical conductivity (ECe) (measured with a conductivity meter), nitrogen (determined using the Kjeltec system), pH in the saturation extract (determined with a pH meter), texture (determined by a Bouyoucos hydrometer), saturation moisture (measured by the weighing method), organic carbon (measured using Walkely and Black titration), lime (determined based on total neutralizing value), gypsum (determined using the acetone method), available water (obtained using the retention curve program based on soil texture and bulk density), and gravel (particles with a diameter >2mm). Elevation was recorded by GPS at the location of each soil profile, and latitude and altitude were recorded to determine slope on the GIS-produced slope map of the area. Study site vegetation was classified using two-way indicator species analysis (TWINSPAN) to determine the main groups. TWINSPAN (a numerical method for simultaneously classifying species and samples based on dividing a reciprocal averaging ordination space) was performed using the vegetation cover data of 14 species obtained from 540 quadrats. The pseudo species cut levels were defined as 0-1-2.5-5-15-25-50. To examine the relationships between plant species and environmental variables, a preliminary detrended correspondence analysis (DCA) was applied to assess the length of the gradient. If the length of the gradient is more than 2 standard deviation (SD) units, a unimodal-based method such as canonical correspondence analysis (CCA) is appropriate (Jongman et al., 1995), whereas if the gradient length is less than 2 SD units, a linear based technique such as redundancy analysis (RDA) is considered suitable (Ter Braak and Prentice, 1988). DCA analysis showed a gradient length of 7.41 (Table 1), therefore the CCA method was used. CCA (Gauch & Wentworth, 1976) is a procedure that combines within one algorithm a reciprocal averaging solution for a correspondence analysis on species site data and a weighted multiple regression analysis on environmental factor-site data (Ter Braak, 1986). In CCA, two matrices were used, one composed of the cover values for species and the other composed of values for environmental variables. The significance of species-environment correlation was identified with the Monte Carlo test (1000 permutations). TWINSPAN and CCA were performed using PC-ORD software.

3. Results

3.1. TWINSPAN

The results of vegetation classification in the study sites using TWINSPAN are presented in Fig 1. Based on the two-way ordered table and the Eigenvalue of each division, the vegetation was classified into three main types as follows:
1- *Artemisia aucheri*
2- *Ephedra strobilacea*
3- *Anabasis aphylla*

3.2. CCA

The relationships between environmental variables and species cover was determined by CCA. Based on the results, 65% of the species-environmental variation was explained by axes 1-3 (Table 1). Axis 1 (Eigenvalue: 0.976) accounted for 32.3% of the variance. The factors corresponding to the first axis were gravel, sand, silt, clay, available water, and organic matter in both layers, pH in the first layer, elevation, and slope (Table 2). Organic matter in the second layer had the highest correlation with this axis.

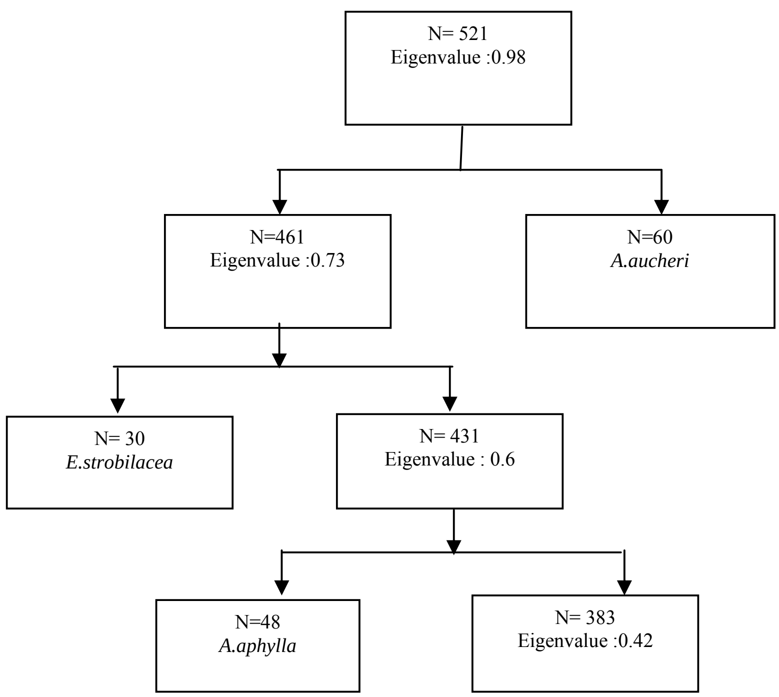

Fig. 1. Dendrogram of TWINSPAN classification for vegetation in the study sites. Data for 19 quadrats were misclassified

Table 1. Detrended correspondence analysis and canonical correspondence analysis

Canonical correspondence analysis for environmental data			
	Axis 1	Axis 2	Axis 3
Eigenvalue	0.976	0.529	0.461
Variance in species data			
% of variance explained	32.3	17.5	15.3
Cumulative % explained	32.3	49.8	65.0
Pearson Correlation, Spp-Envt	0.994	0.985	0.932
Detrended correspondence analysis			
Length of gradient	7.41	2.29	1.43

Total variance in the species data: 3.024

Table 2. Correlations for the environmental variables in CCA

	CCA (Axis)		
Environmental variables	1	2	3
Elevation	0.716	-0.099	0.382
Gravel (1)	-0.523	-0.050	-0.161
Gravel (2)	-0.539	0.036	-0.410
Saturation percentage (1)	-0.300	-0.080	0.630
Saturation percentage (2)	0.360	0.485	0.278
p.H (1)	0.361	-0.051	-0.218
p.H (2)	0.286	-0.133	0.350
Gypsum (1)	-0.157	-0.296	-0.930
Gypsum (2)	-0.207	-0.321	-0. 817
Carbon to nitrogen ratio (1)	0.033	0.001	0.253
Carbon to nitrogen ratio (2)	-0.028	-0.348	-0.868
Sand (1)	-0.609	0.042	-0.203
Sand (2)	-0.906	-0.116	-0.134
Silt (1)	0.560	-0.060	0.258
Silt (2)	0.904	0.086	0.180
Clay (1)	0.626	0.100	-0.267
Clay (2)	0.831	0.233	-0.071
Available water (1)	0.569	-0.075	0.236
Available water (2)	0.843	0.145	0.160
Electrical conductivity (1)	-0.283	0.527	-0.146
Electrical conductivity (2)	-0.139	0.878	-0.410
Lime (1)	-0.183	0.103	0.483
Lime (2)	-0.218	-0.048	0.399
Organic matter (1)	0.925	-0.046	0.043
Organic matter (2)	0.949	-0.006	0.209
Slope	0.894	-0.060	0.148

Signs 1 and 2 indicate the first (0-10 cm) and the second (10-80 cm) soil layers respectively

17.5% of the variation was explained by axis 2 (Eigenvalue: 0.529). Saturation moisture in the second layer and ECe in both layers were represented by the second axis. ECe in the second layer had the highest correlation with this axis. 15.3% of the variance was explained by the third axis (Eigenvalue: 0.461). Saturation moisture in the first layer, pH in the second layer, and gypsum, C/N ratio, and lime in both layers were associated with the third axis, among which gypsum in the first layer had the highest correlation with this axis. The correlations between axes 1, 2, 3 and species-environmental factors were 0.994, 0.985, and 0.932 respectively. Results of the Monte Carlo test for the first three axes was highly significant ($P<0.001$). To better explain and analyze the most influential environmental factors on vegetation cover, the position of species was described based on axes I-II (Fig. 2) and I-III (Fig. 3). *A.aucheri* (and *A.microphysa* as the second most abundant species in the *A.aucheri* type) were characterized by high silt and organic matter in both soil layers, clay and available water in the second layer, high elevation, and slope. These factors had a lesser effect on the *S.barbata* cover. The *A.aphylla* cover was mostly associated with high soil salinity (ECe) in both layers and saturation moisture in the second layer. *E.strobilacea* was characterized by a high content of gypsum in both layers, C/N in the second layer, and a low saturation moisture content in both layers. The cover of *P.harmala, A.scorpius, Z.europterum, I.songarica, S.tomentosa, A.sieberi, S.arbuscula, E.ceratoides and A.glaucacanthus* was mainly affected by a high rate of sand in both layers.

4. Discussion

The results indicate that the distribution of vegetation is closely related to a variety of edaphic and topographic factors. Among the soil attributes, texture, available water, saturation moisture, organic matter, gypsum, ECe and C/N ratio greatly affected the distribution of plants. *A.aphylla* was found to be an important indicator of soils with high salinity and saturation moisture content. Xu et al. (2005) found that *A.aphylla* indicates habitats of high soil salinity, a somewhat high or medium water-table, and a reasonable clay grain content in a clay desert. In arid and semi-arid zones, soil salinity is an important factor in the distribution of plant species (Caballero et al., 1994; Allen & Mcintosh, 1997). Salinity affects seed germination (Azarnivand et al., 2006) and nutrient availability by modifying the retention, fixation, and transformation of the nutrients in soils, interfering with the uptake and/or absorption of nutrients by roots due to ionic competition and reduced root growth, and disturbing the metabolism of nutrients within plants, mainly through water stress. *E.strobilacea* reflected a high soil gypsum content, a high C/N ratio, and a low saturation moisture content. Jafari et al. (2004) found a considerable amount of gypsum in the habitat of *E.strobilacea*. The C/N ratio is affected by such soil attributes as salinity, lime, and gypsum. Soil C/N affects soil structure by influencing the metabolism of bacteria in the soil (Bohn et al., 1985). Studies have shown that nitrogen nitrification is retarded, suppressed, or inhibited completely by salinity (Laura, 2002; Singh & Taneja, 1976), but, in turn, a low gypsum content in soil stimulates the soil microorganisms responsible for nitrogen mineralization. High rates of gypsum, however, may lead to lower levels of N mineralization (Singh & Taneja, 1977) and a higher C/N ratio. The cover of *A.aucheri* was characterized by a gradient of increasing elevation and slope, high levels of organic matter and available water, and a gradient of soil from light sand to heavy clay. Jafari et al. (2004), however, revealed that *Artemisia aucheri-Astragalus.sp* occurs in light textured soils. Elevation (Azarnivand et al., 2003) and rainfall (Yaghmaei et al., 2008) have also been recognized as factors affecting the distribution of *A.aucheri*. A light soil texture was found to be the most important factor affecting the distribution of *P.harmala, A.scorpius, Z.europterum, I.songarica, S.tomentosa, A.sieberi, S.arbuscula, E.ceratoides, and A.glaucacanthus.* Basically, soil texture affects the distribution of vegetation under identical climatic conditions (Liao & Chang, 2004). In addition, soil texture can affect plant growth, seed germination, and seedling establishment (Hook et al., 1994), functional type, and plant composition (Anderson, 1983). This is because the rate and depth of leaching (e.g., NO3-N) (Gaines & Gaines, 1994), the movement and availability of air and water in soil (Hunt & Gilkes, 1992), the dynamic processes of soil organic matter (Bossata & Agren, 1997), water supply, soil organic carbon and nitrogen, and mineralization (Bossata & Agren, 1997) are all highly influenced by soil texture. Overall, the degree of relation between vegetation and environmental factors results from the ecological requirements, tolerance range, and habitat conditions of plants. The determination of plant species indicating environmental factors in a given site will lead to the efficient selection of adaptable species for the improvement and reclamation of that and similar sites.

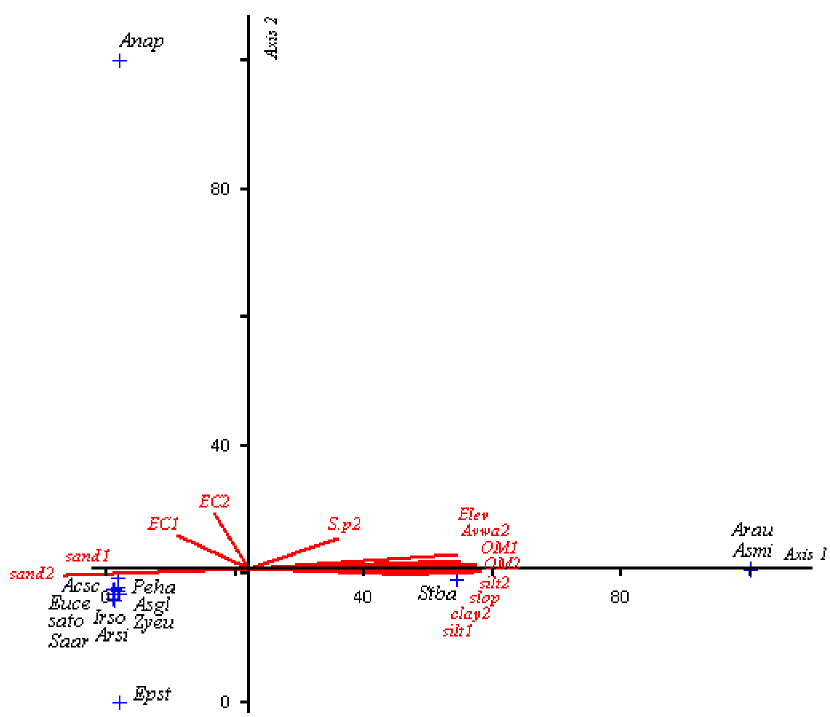

Fig. 2. CCA-ordination of species in relation to environmental variables based on axis I and II. Cut off r^2 value was set as 0.4

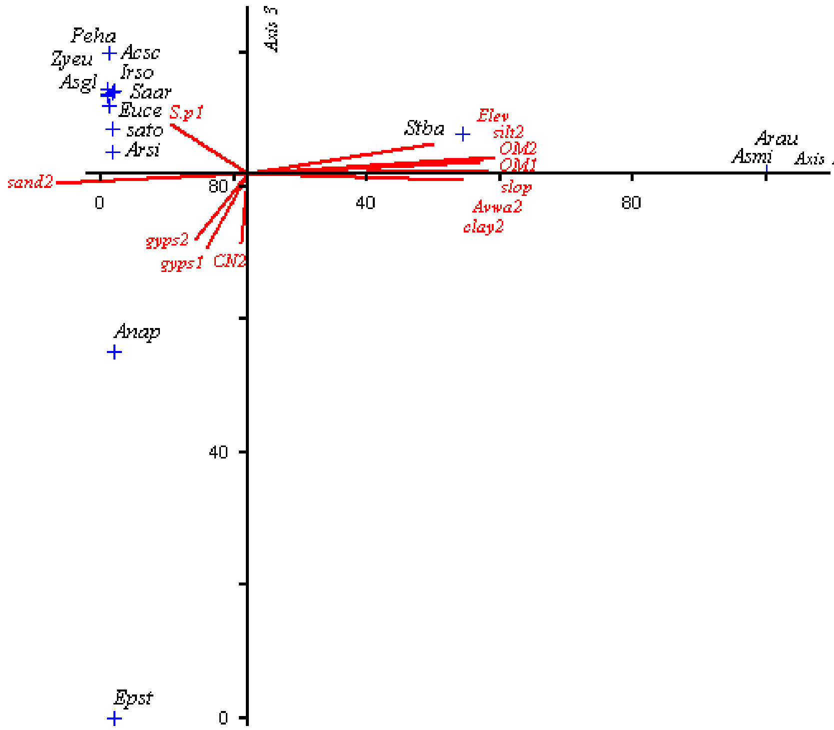

Fig. 3. CCA-ordination of species in relation to environmental variables based on axis I and III. Cut off r^2 value was set as 0.4

Table 3. Topographic and edaphic characteristics of the study sites (vegetation types)

Study sites (vegetation types)	Gravel (1)%	Gravel (2)%	Saturation percentage (1)	Saturation percentage (2)	pH(1)	pH(2)	Gypsum (1)%	Gypsum (2)%	C/N (1)	C/N (2)	Sand (1)%	Sand (2)%	Silt (1)%	Silt (2)%
A.sieberi- S. tomentosa	17	19	36.6	36	7.3	7.83	0	0	5.3	4.76	69.4	73.4	21.3	17.3
A.sieberi- E.strobilacea	14	21	32	28.2	7.64	7.31	61.74	63.43	3.94	75.71	66.4	81.4	23.3	11.3
A.aphylla- A.sieberi	12	18	35	39	7.43	7.31	2.06	0	11.87	3.51	63.4	68.4	26.3	21.3
A.sieberi-S. arbuscula	12	21	39	27	7.38	7.43	0	29.4	1.38	2.76	57.4	83.4	33.3	11.3
A.sieberi- P.harmala	11	19	37	34	7.59	7.78	0	0	9.5	4.52	63.4	77.4	27.3	17.3
A.sieberi. Z.europterum	11	14	39	32	7.9	7.75	0	0	11.75	4.06	53.4	70.4	37.3	22.3
A.sieberi-E. ceratiodes	16	9	46	32	7.06	7.72	1.01	0.11	57.1	21.07	71.4	77.4	21.3	16.3
A.sieberi-I. songarica	8	14	38	36.4	7.19	7.16	0	0	6	3.45	43.4	63.4	47.3	27.3
A.aucheri	8	10	36	36	7.67	7.69	0	0.21	16.52	12.45	41.4	41.4	46.9	45.3

Continued-

Study sites (vegetation types)	Clay (1)%	Clay (2)%	Available water (1)%	Available water (2)%	Electrical conductivity (1) (ds/m)	Electrical conductivity (2) (ds/m)	Lime (1)%	Lime (2)%	Organic matter (1)%	Organic Matter (2)%	Mean Elevation (m)	Slope Classes%
A.sieberi-S. tomentosa	9.3	9.3	15.5	8.68	16	1.98	17.57	13.57	0.0758	0.275	1850	0-2
A.sieberi-E.strobilacea	10.3	7.3	10.27	5.11	3.24	6.01	9.07	9.07	0.275	0.091	1940	0-2
A.aphylla-A.sieberi	10.3	10.3	10.83	9.88	16.5	30.37	23.3	18.57	0.229	0.229	2010	0-2
A.sieberi-S. arbuscula	9.3	5.3	12.09	3.26	10.7	5.3	22.8	13.5	0.107	0.153	2074	0-2
A.sieberi-P.harmala	9.3	5.3	10.8	6.86	0.673	1.17	22.8	23.57	0.458	0.229	2186	0-2
A.sieberi. Z.europterum	9.3	7.3	13.07	9.29	0.78	1.047	34.8	43.3	0.427	0.382	2262	0-2
A.sieberi-E. ceratiodes	7.3	6.3	8.94	6.69	0.72	0.87	12.82	15.3	0.275	0.305	2318	2-5
A.sieberi-I. songarica	9.3	9.3	16.92	10.99	1.01	0.52	34.8	50.32	0.275	0.382	2420	2-5
A.aucheri	11.7	13.3	17.13	16.6	0.624	1.6	20.32	20.07	0.917	0.962	2618	2-10

Signs 1 and 2 indicate the first (0-10 cm) and the second (10-80 cm) soil layers respectively. Organic matter was calculated by multiplying %organic carbon by a factor of 1.724.

Table 4. The cover percentage of the plant species in the study sites

Study sites (vegetation types)	*Artemisia sieberi*	*Salsola tomentosa*	*Ephedra strobilacea*	*Anabasis aphylla*	*Salsola arbuscula*	*Peganum harmala*	*Zygophyllum europterum*	*Acantholimon scorpius*	*Eurotia ceratiodes*	*Astragalus glaucacanthus*	*Iris songarica*	*Stipa barbata*	*Artemisia aucheri*	*Astragalus micriphysa*
A.sieberi-S. tomentosa	6.6	1.1	-	-	-	-	-	-	-	-	-	-	-	-
A.sieberi-E.strobilacea	5.1	-	4.8	-	-	-	-	-	-	-	-	-	-	-
A.aphylla-A.sieberi	2.9	-	-	3.3	-	-	-	-	-	-	-	-	-	-
A.sieberi-S. arbuscula	9	-	-	-	1.4	-	-	-	-	-	-	-	-	-
A.sieberi-P.harmala	5.2	-	-	-	-	2.62	-	-	-	-	-	-	-	-
A.sieberi. Z.europterum	12.9	-	-	-	-	-	2.6	1.9	-	-	-	-	-	-
A.sieberi-E. ceratiodes	10.4	-	-	-	-	-	-	-	2.1	0.52	2	-	-	-
A.sieberi-I. songarica	16.6	-	-	-	-	-	-	2.1	-	-	2.7	0.61	-	-
A.aucheri	-	-	-	-	-	-	-	-	-	-	-	0.7	23	1.5

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