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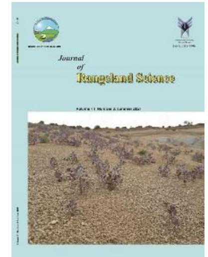

Research and Full Length Article:

Effects of Topography and Soil Variables on Abundance of *Onobrychis chorassanica* Bunge. in Kardeh and Kurtian Rangelands, Mashhad, Iran

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Abstract. Environmental factors have major impact on the distribution and yield of plant species. For this purpose, the responses of Khorasanian sainfoin (*Onobrychis chorassanica* Bunge.) were evaluated with regard to some environmental factors in habitats of Khorasan Razavi province in 2018- 2020. Generalized Additive Model (GAM) was used to investigate the response of this species to soil and topographic factors. The results indicated that *O. chorassanica* exhibited a substantial response to some environmental factors in its habitat. The response pattern of this species includes the gradient of soil, Total Neutralizing Value (TNV) as well as soil clay percent, followed by the monotonic increase model. Therefore, with the increase in the values of these factors, its vegetation cover percent increased. In contrast, the response of this species along with the gradient of soil sand percent followed the monotonic decrease model and with enhancement of the factor amount, the presence of *O. chorassanica* decreased. Soil studies have revealed that this species is mainly distributed on loamy to sandy loam soils. The response pattern of *O. chorassanica* along with the gradient of Organic Carbon content (OC%) and soil litter percent complied with unimodal model and its optimal growth levels for these factors were 0.4% and 30%, respectively. The geographical response of this plant also displayed that the vegetation cover percent of the studied species increased in the western and north aspects and is rarely apparent in the southern and southeastern aspects. Investigation of *O. chorassanica* response on gradient of topographic and soil factors provided valuable information for determining ecological needs of this species, which can be considered in vegetation management and range improvement operations in similar areas.

Key words: *Onobrychis chorassanica* Bunge., Ordination, Ecological factors, Generalized additive model, Response curve

Introduction

Plant communities have been altered over time due to changes in the environment factors (climate change, natural disturbances, etc.) and human activities (Pickett and White, 1985). With regard to production level, recent surveys confirm that the Iranian rangelands have gone through a downward trend (Heidari Sharifabad and Torknejad, 2000; Dashti *et al.*, 2018). Some factors such as excessive and out of season grazing in different areas and the disproportionate number of livestock with forage production capacity in the Iranian rangelands have reduced the population of the palatable plants (such as *Onobrychis chorassanica* Bunge.) in the rangelands, leading to the diminished power to supply the livestock (Heidari Sharifabad and Torknejad, 2000; Dashti *et al.*, 2020). On the other hand, the recognition of plant ecological attribute and their reactions to environmental factors could provide valuable information about ecology and introduction of suitable species for rangeland improvement, forage production, and vegetation management in similar areas. Ecologists believe that the presence and distribution of plant communities in rangeland ecosystems are not accidental; though climatic conditions, soil, humidity, altitude and human factors play an outstanding role in their development (Leonard *et al.*, 1984). Ecological knowledge is obtained by studying the environmental factors that affect plant distribution. In arid and semi-arid areas, environmental factors have a great contribution to plant distribution (Gholinejad *et al.*, 2020).

Analysis of interrelationship between plants and environmental factors has always been considered as a primary issue in ecological studies (Guisan and Zimmermann, 2000). Nowadays, various methods have been initiated to study the ecological factors and the relationship between plant species dispersion and environmental factors, some for the possibility of species presence and others to investigate factors affecting species distribution and spatial prediction of suitable habitat for species establishment (Bakkenes, 2002; Peterson 2001; Berg *et al.*, 2004; Guisan *et al.*, 2002; Robertson, 2003; Engler *et al.*, 2004).

O. chorassanica is a perennial and herbaceous plant with height of 25 to 70 cm from the Fabaceae family. The distribution of this plant is limited in Iran, Afghanistan and Central Asia (Rechinger, 1984). The regional distribution of *O. chorassanica* is mainly concentrated in the northern and northeastern regions of Khorasan Razavi province, Iran including the Torogh Dam area of Mashhad (1350 m above sea level), the heights of Hezar Masjid Mountains of Kalat including the northern heights of Qarasu (1200 m) and the northern aspect of Allah Akbar heights of Dargaz city (1200 m). *O. chorassanica* like other perennial sainfoin species is not present in the southern regions of the province (Amirabadizadeh, 2009). Gholami and Tavakoli (2004) also showed that *Onobrychis verae* in the northern slopes in the form of local spots with perennial grasses create very suitable plant communities.

Even though, numerous studies have been conducted on the autecology of plant species in Iran; however, the response expression of the studied species to the gradient of environmental changes has mainly remained descriptive. The study of perennial sainfoin species in Khorasan Razavi province revealed that these species are situated in a certain altitude range so that *O. chorassanica* habitats have been reported in the altitude range of 750 to 1950 m above sea level (Amirabadizadeh, 2009). The altitude above 1300 m has a considerable effect on the reduced presence of this species. The results of a report by Gholami and Tavakoli (2004) indicated that *Onobrychis verae* is mainly found in mountainous areas which are mainly geologically related to calcareous formations and relatively deep soils. They also showed that the altitude range of its habitats varies between 1250 to 2600 m. asl. Karamian *et al.* (2010) reported that habitats of *O. melanotricha* in Hamadan province, Iran were observed in the altitude range of 1935 and 2241 m asl. Abarsaji *et al.* (2007) observed the presence of Kopetdaghi Sainfoin (*Hedysarum kopetdaghi* Boriss.) in calcareous lithosol soils of rangelands of Golestan province, Iran. Their results also showed that the habitats of this species appear mainly in soils with silty loam texture without salinity. Other studies that have descriptively expressed the habitat mannerism of plant species can be examined: Autecology of *Salsola orientalis* S.G.Gmlin (Dashti *et al.*, 2009), *Eremurus spectabilis* M.B. (Dashti *et al.*, 2005).

Various mathematical models have been applied to study the reaction of plant species. Among them, the Canonical Correspondence Analysis (CCA) has been considered to establish the factors affecting the distribution and the Generalized Additive Model (GAM) to study the response of plant species to environmental elements (Traoré *et al.*, 2012). The presence of smoothing agents in the GAM has led to the ability of this model to analyze ecological data and nonlinear relationships between different variables (Guisan *et al.*, 2002). Therefore, this model maximizes the quality of response prediction while reducing the mean squares of error by providing more information about the relationships between variables and reaction of the species to environmental elements (Vaziri Nasab *et al.*, 2013; Salehi *et al.*, 2012).

Mirdavoodi (2013) studied the reaction of significant plant species to the environmental factors in western oak forest by applying a GAM. His findings indicated that the reaction of invasive species to overgrazing and effective factors such as soil bulk density is a monotonic increase response. Heidari *et al*. (2018) found that *Bromus tomentellus* and *Achillea millefolium* had different reactions to sea level altitude so that the soil sand content had a positive effect on the distribution of *B. tomentellus* while this variable had an adverse effect on the presence of *A. millefolium*. Considering the significance of forage and adaptation of *O. chorassanica* in some areas of Khorasan Razavi (north-east of Iran), it appears imperative to address the ecological characteristics and study the presence of this valuable species in the growing areas for better management and reproduction.

This research aimed to study the ecological needs of *O. chorassanica* and investigate the response of this species to the variations in soil and topographic factors using the Generalized Additive Model (GAM) in the habitats in Khorasan Razavi province, Iran. Phenological study of this plant was also evaluated.

Materials and Methods

In order to study the topography and some soil variables affecting *O. chorassanica*, two habitats called Kardeh Dam (40 km north of Mashhad, located on the southern aspect of Hezar Masjed mountain range) and Kortian (20 km southwest of Mashhad, located on the northern aspect of the Binaloud mountain range) in Khorasan Razavi province (north-east of Iran) in 2018 were selected (Table 1 and Figs. 1, 2). Sampling of the vegetation was done by the systematic-random method (Arzani and Abedi, 2015). As a result, depending on extent of the gradient of environmental changes in each habitat, five transects with the same distance from each other were selected and on each one of them, six plots (1x1 m) with equal distances were established and the geographical location of each plot was recorded.

The length of transects was approximately 1 km and their distance was 200 m. After the sampling network in each ecological plot was established, the plant density and the canopy cover percent of each plant species in the plots and the annual production of *O. chorassanica* were measured. All the variables were measured at the flowering stage. Plants density was determined by counting and their canopy cover percent was theoretically estimated (ocular estimate). The current year production of *O. chorassanica* was also measured by clipping method. Similarly, in each plot, the total canopy cover, rock & gravel, bare soil and litter percent were also calculated.

For the purpose of investigating the effect of environmental factors on the dispersal of *O. chorassanica*, a composite soil sample was gathered from each plot to the rooting depth of the plant (0-40 cm). The soil physical and chemical properties including texture, pH, Total Neutralizing Value (TNV%), Organic Carbon Content (OC%) and Saturated Moisture percent (SP) were measured (Robertson *et al.*, 1999). The geographic aspect variable was determined based on four main aspects of 0, 90, 180, 270, degrees (A) and a cosine function were applied to transform into quantitative data ranging from 0 to 2 (A`) using the following equation (Beers et al., 1966). The results of this method provide easier interpretation (Palmer, 1993).

$$A` = \cos(45-A) + 1$$

Plant phenology was studied with the aim of managing livestock in rangelands, especially determining the time of entry of livestock into the rangeland as well as the time of seed collection. For this purpose, the plant growth calendar was recorded for three years (2018-2020) from the beginning of the growing season (early March) and for a total of 10 random plants (marked inside the plots) every two weeks at the studied habitats. Finally, the phenological diagram was drawn in conformity with the Embrothermic curve.

Table 1. Physiographic, climatic, soil and vegetation types of two habitats of *O. chorassanica* in Khorasan Razavi province, Iran

Characteristics	Kardeh	Kortian
Latitude	36°38′39″ to 36°38′30″ N	36°09′34″ to 36°09′04″ N
Longitude	59°40′27″ to 59°40′10″ E	59°32′22″ to 59°31′35″ E
Plant types	*Poa bulbosa, Centaurea virgate Onobrychis chorassanica,*	*Centaurea virgate, Poa bulbosa, Gundelia tournefortii*
Chorotype	Irano-Tourani region	Irano-Tourani region
Ecological zone type	Steppe and semi-steppe	Steppe and semi-steppe
Mean annual precipitation (mm)	248	240
Mean annual temperature (ºC)	14.5	15.0
Climate*	Cold semi-arid	Cold semi-arid
Altitude (m. asl)	1200-1400	1100-1500
Mean slope (%)	18	22
Geographical aspects	North and West-north	East and East-north
Landform	Mountain, hill, plain	Mountain, hill, plain
Soil texture	Loam	Sandy loam
Lithology	Calcareous	Calcareous

* Climate conditions according to Emberger classification

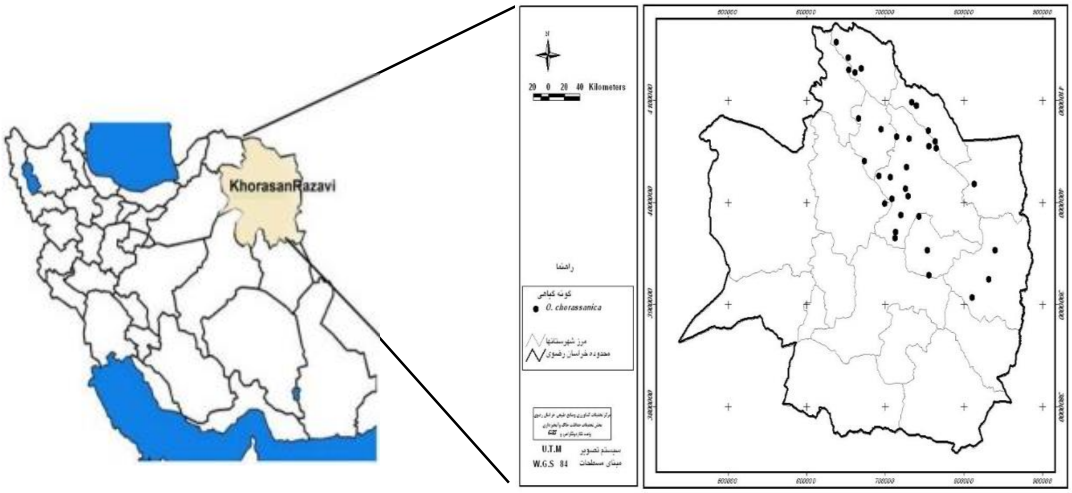

Fig 1. *O. chorassanica* distribution in Khorasan Razavi province, Iran

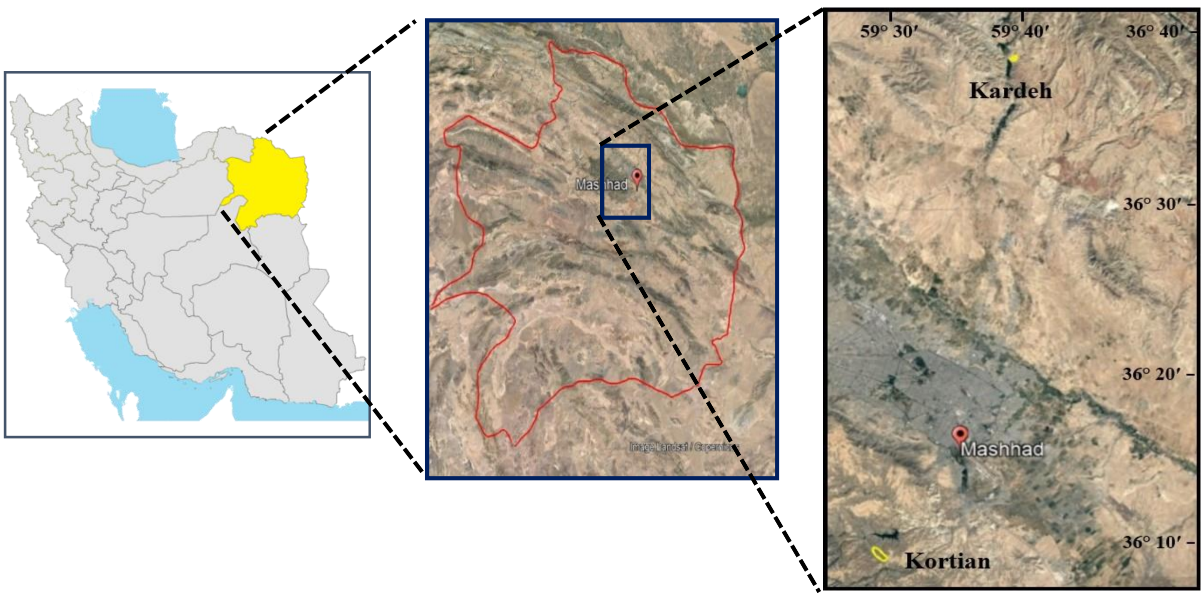

Fig 2. Study area of *O. chorassanica* in map of Iran and Khorasan Razavi province

Data analysis

For investigation of the relationship between effective and significant environmental variables and plant vegetation and to select the appropriate linear and nonlinear method, Detrended Correspondence Analysis (DCA) was performed on vegetation data (response data), and the gradient length was determined. Given the length of the first axis gradient (which was greater than 4), the Canonical Correspondence Analysis (CCA) method was used as the nonlinear method. At data preparation stage, the nominal and sequential variables such as soil texture and the relative data in the column related to each of the factors were initially identified. The outcome of this division was 21 environmental variables that were classed in four groups of soil (texture, pH, TNV, SP, bare soil, litter, gravel) for easier interpretation; topography (altitude, slope percent and aspect); rock outcrop (rock percent as a measure of rock habitats) and spatial correlation between sample plots (Borcard *et al.*, 1992) were evaluated. For the analysis of the data in this section, Canoco software version 4.5 was used (Ter Braak and Smilauer, 2002).

For plotting the response curve of *O. chorassanica* to environmental factors, the GAM was applied (Bakkenes *et al.*, 2002; Traoré *et al.*, 2012; Godefroid and Koedam, 2004). As for ranking the variables affecting the performance of the species, the Akaike Information Criterion (AIC) was used as a measure of good fit (Akaike, 1974). Thus, the smaller the AIC value, the variable has more effect on the canopy cover percent, or the proposed model is the most suitable model for fitting the species response curve. In this study, the canopy cover percent of *O. chorassanica* was used to explore the relationship between species and the environment, and the ecological range was calculated as a function of the Gaussian response (Ardekani, 2009).

Results

Vegetation Attributes

Owing to the vegetation cover percent of the plant species, the dominant vegetation type in the two habitats was virtually similar in a way that *Poa bulbosa*, *Onobrychis chorassanica*, *Centaurea virgata*, and *Gundelia tournefortii* were the dominant vegetation in the area. The accompanying plants of *O. chorassanica* in the studied habitats included 73 species belonging to 60 genera and 25 plant family. The average characteristics of soil ground cover in the studied habitats as well as some characteristics of *O. chorassanica* are presented in Table 2. The average canopy cover percent of some important and dominant species is also exhibited in Fig. 3.

Table 2. Average characteristics of soil surface cover and *O. chorassanica* canopy cover in habitats (Mean± SE)

Habitats	Total canopy cover (%)	Litter (%)	Bare soil (%)	Rock and gravel (%)	Canopy cover (%)	Density (ha.)	Biomass (Kgh^{-1})
Kardeh	28.4±1.1	12.4±8.2	37.0±13.4	20.5±11.8	3.8 ± 2.5	2700±2200	109.2±87
Kortian	29.7±1.3	36.7±29.5	33.4±20.7	5.9±3.1	2.0 ± 1.4	791.7±590	71.5±54

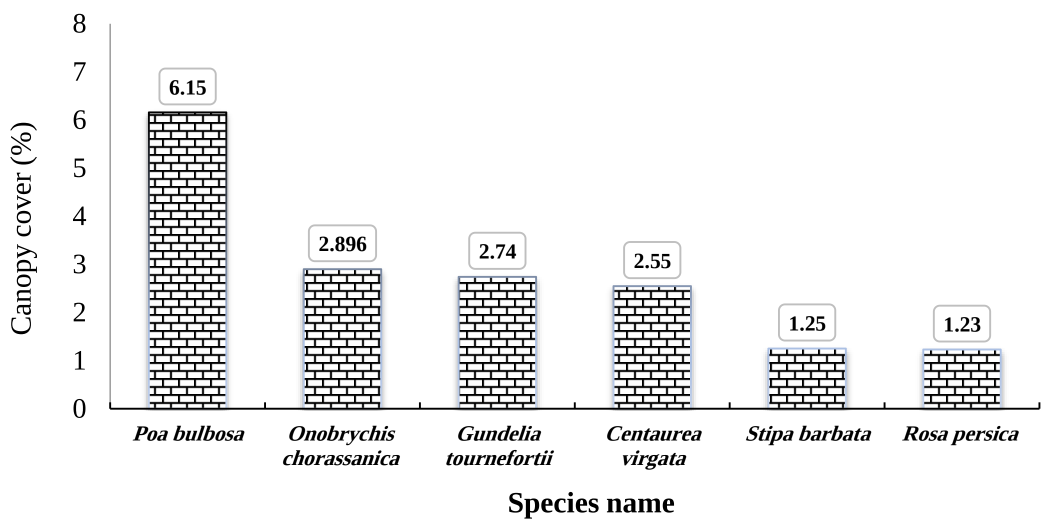

Fig 3. Mean canopy cover percentage for major species in habitats

Habitat characteristics

The habitats of *O. chorassanica* are situated on the northern aspect of Binalood mountain range and the heights of Hezar Masjid mountain range, which are mainly rocky mountainous and consist of calcareous formations (mainly Marl) with comparatively shallow soil and fairly high rock protrusions. The range of altitude variation of this species was from 750 to 1950 m above sea level. The canopy cover of this species was reduced dramatically by the increasing altitude above 1300 m; because the changes in altitude in its habitats are not so pronounced, the reduction in the cover percent can also depend on other elements such as soil type. The results also showed that the range of changes in soil pH, TNV, OC and SP was 7.6- 8.8, 22.2- 44.6%, 0.1-0.4%, and 27.7-42.47%, respectively. Loamy to sandy loam soil texture and rock protrusion percent of 0-25% were observed. The results of *O. chorassanica* habitats characteristics as well as the lowest and highest amounts of some ecological factors are shown in Table 3.

Table 3. Minimum and maximum environmental factors in *O. chorassanica* habitats

Factors	Sand %	Silt %	Clay %	TNV %	SP %	OC %	Bare (%)	Gravel %	Litter %	Slope %	pH	EC ds/m	Alt.* (m)	Pre.** (mm)
Min.	15.0	24.0	9.0	3.2	27.7	0.1	4.0	0.0	1.0	5.0	7.6	0.7	1250	226
Max.	63.0	60.0	37.0	44.6	42.4	1.4	85.0	50.0	85.0	31.0	8.1	1.8	1330	258
Mean	42.7	38.1	19.2	23.7	33.3	0.6	35.8	15.6	20.5	17.7	7.8	1.1	1306	244

*Altitude, **Precipitation

Relationships of species distribution with environmental factors

The investigation into the effect of a set of environmental factors on variation in vegetation communities, using the forward selection method in canonical classification, resulted in selection of four variables from 21 primary variables. The chosen variables were the total neutralizing value (lime) percent, aspect, slope percent and litter percent (Table 4).

Table 4. Important and influential factors on vegetation cover changes in *O. chorassanica* habitats

Selected factors	Variance	F values
Total Neutralizing Value (TNV%)	3.8	1.7**
Aspect	3.3	1.5**
Litter (%)	3.0	1.4*
Slope (%)	3.0	1.4*

*, ** significant at 0.05 and 0.01 significant levels, respectively

The findings indicated that the total proportion of variance in the vegetation (using CCA ordination) is equal to 8.85. Taking into account all the selected variables as the constraining variables, considering the spatial correlation as the accompanying variable (covariates) and eliminating the effect of this variable on vegetation variations, the above model demonstrated 13.1% of the total variance. The first axis with an eigenvalue of 0.41, 4.6% and the second axis with an eigenvalue of 0.32, 3.65% justify the entire vegetation variations. The conclusions of CCA were on the first and second axes and the major factors established in the forward selection method are presented in Fig. 4. The distance of points from the coordinate axes shows the potency or weakness of the relationship. The larger the length of vector and the smaller their angle with the axis, the stronger the correlation between factors and plant species with the axes and its relationship with the features of the axes.

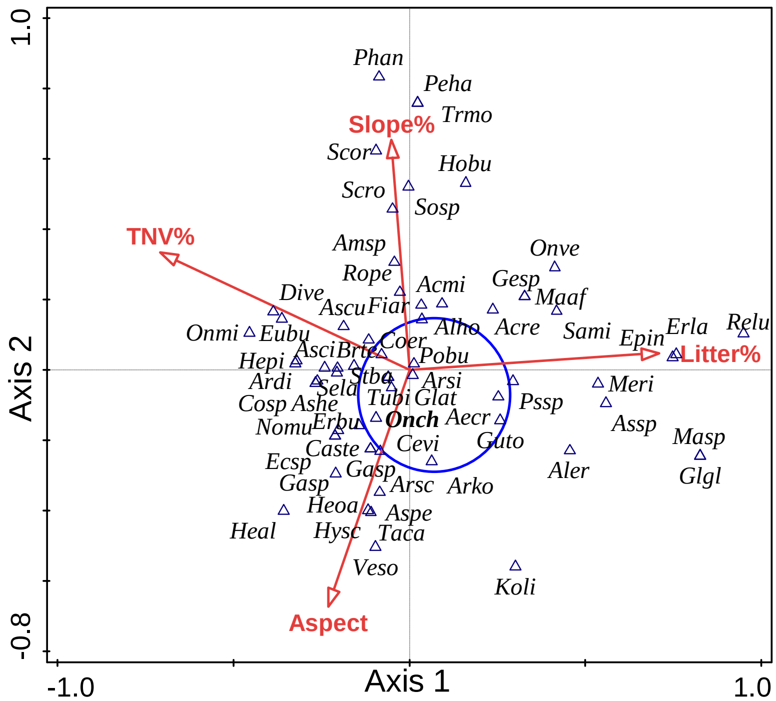

Fig. 4. Plant species distribution related to ecological gradients

As it can be seen in Fig. 4, plant species that were mostly present in the plots with *O. chorassanica* are *Artemisia sieberi* Besser, *Poa bulbosa* L., *Centaurea virgata* Lam., *Stipa barbata* Desf., *Aegilops crassa* Boiss., *Gladiolus atroviolaceus* Boiss. and *Tulipa biflora* Pall.

The correlation between canopy cover percent of *O. chorassanica* and ecological factors studied was examined. The findings indicated that the canopy cover percent was positively and largely correlated with factors such as lime percent, soil silt percent, clay percent, altitude, percentage of rock and gravel and soil SP content. The soil OC and soil sand percent as well as the slope have a negative correlation (Table 5).

Table 5. Correlation coefficient between environmental factors and canopy cover percentage of *O. chorassanica*

Factors	Correlation coefficient
Total Neutralizing Value (TNV%)	0.855**
Silt (%)	0.600*
Altitude (m a.s.l.)	0.545*
Rock and Gravel (%)	0.538*
Saturated Moisture percentage (SP%)	0.532*
Clay (%)	0.460*
Organic Carbon Content (OC%)	-0.617**
Sand (%)	-0.599**
Slope (%)	-0.491*

*, **significant at 0.05 and 0.01 significant levels, respectively

O. chorassanica's response curve to environmental factors

The application of the GAM obtained with Poisson error distribution for each of the environmental variables revealed that some of the studied variables had a significant effect on the cover percent of *O. chorassanica* (Table 6).

Table 6. The results of fitting the Generalized Additive Model for each of the significant variables

Factors	F value	AIC#
Sand (%)	3.3**	244.73
Clay (%)	7.6**	203. 26
Total Neutralizing Value (TNV%)	5.2**	224.6
Organic Carbon Content (OC%)	13.3**	170.96
Aspect	3.8*	236.44
Litter (%)	3.5*	240.75

AIC: Akaike Information Criterion

*, ** significant at 0.05 and 0.01 significant levels, respectively

The response of *O. chorassanica* in relation to the variable of sand percent in soil texture followed the monotonic decrease model and with increasing the amount of this factor, its presence and canopy cover percent diminished (Fig. 5a). Contrarily, the response of *O. chorassanica* to the percentage of clay and TNV is increasing (Monotonic increase) and with increasing the amount of these factors, its frequency and canopy cover percent increased (Figs. 5b, 5c).

The investigation of the canopy cover percent in relation to the variables of soil OC content and litter percent revealed that the response of *O. chorassanica* was unimodal. Hence, with increasing the percentage of OC and litter up to 0.4 and 30% respectively, the abundance of *O. chorassanica* species increased and then, with increasing the amounts of these factors, they exhibited a decreasing trend. With respect to OC percent, the presence of this species started from 0.2% and continued up to 1.4%, and outside the studied range, it did not exist (Fig. 5d). The findings similarly indicated that the presence of this species started from 1% of litter and continued up to 85% and outside the studied range, the dispersal of the species was not observed (Fig. 5f). The geographical response of *O. chorassanica* in the studied habitats almost followed the unimodal model so that the frequency and canopy cover of *O. chorassanica* increased in the western aspects, it was almost constant in the northern slopes and it decreased in the southern and southeastern facing slopes (Fig. 5e).

The findings also indicated that the presence of *O. chorassanica* in the habitat of Kardeh Dam was primarily in the northern, northwestern and western aspects and in Kortian in the eastern, northeastern and southwestern aspects and the existence of the species was not observed in the southern and southeastern facing slopes.

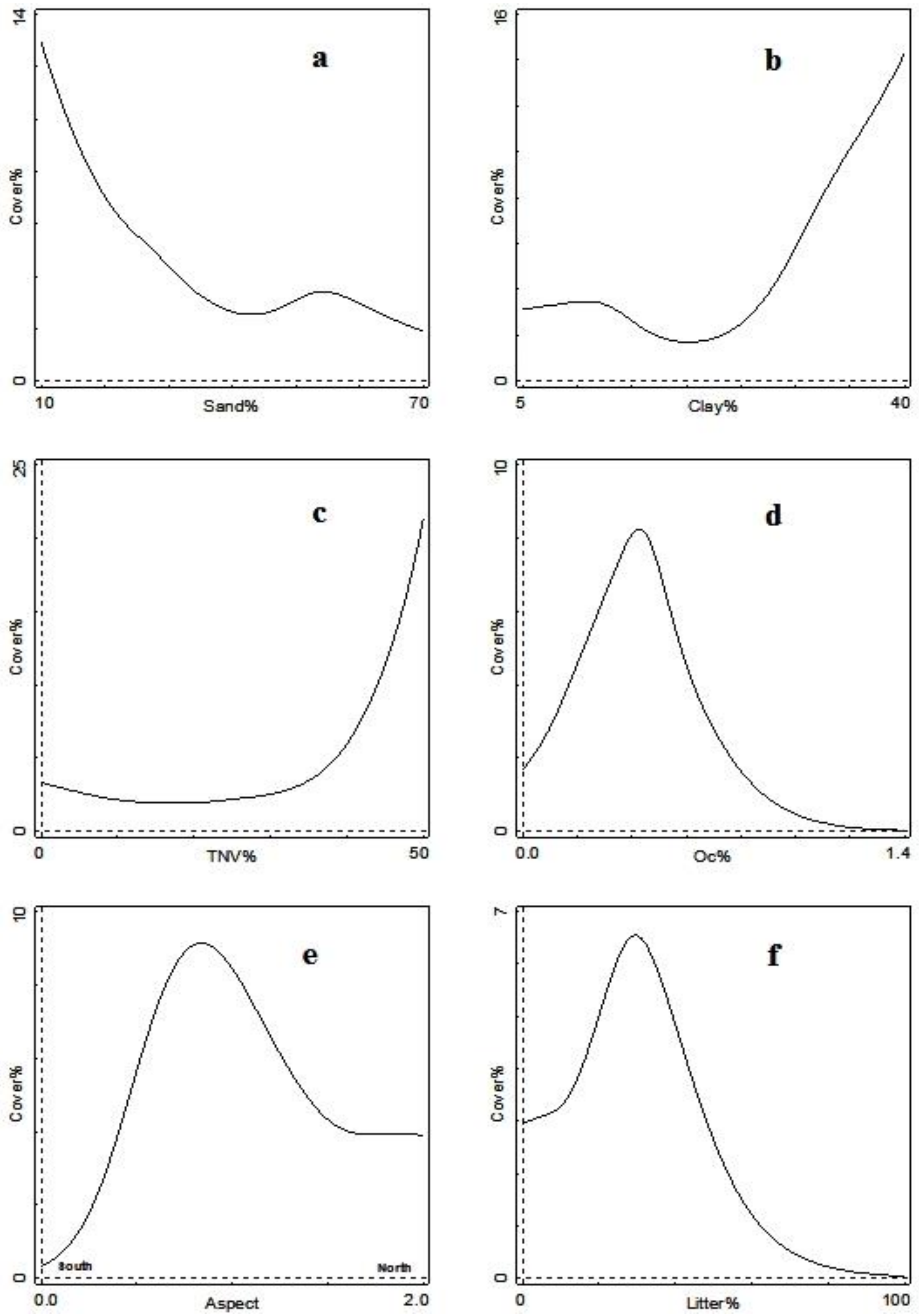

Fig 5. Response curves of *O. chorassanica* to the significant variables
Sand (a), Clay (b), TNV (c), OC (d), Aspect (e), Litter (f)

Phenology of *O. chorassanica*

The findings of three years of phenological investigations of *O. chorassanica* in studied habitats revealed that the germination of the seeds is epigeal, so with the gradual warming from early-April, the cotyledons emerged from the soil surface and seedlings sprouted. Initially, it begins with the appearance of two small cotyledon leaves. After the emergence of 5 to 6 simple leaves, the first three-leaflets and then, one to two 5-leaflets are formed. Plant growth is slow in the first year and completes its growth as the root gets established. The time span of entering the reproductive stage in annual plants is somewhat long and in spite of the modest vegetative growth, they entered the flowering stage in mid-June. The seeds were gradually formed from late June and eventually fell by mid-August. With warming weather and drought, the leaves and then the inflorescence axis gradually dried out and the plant entered the summer recession by September. The life form of *O. chorassanica* is hemicryptophyte; therefore, the regrowth of plants restarts with the onset of rainfall throughout September and early autumn from the vegetative buds of the soil surface at the collar. The plants have deeper and stronger roots in the second year of their growth. With the rise in temperature from the first half of March, the vegetative growth of plants started from the crown and with the increase of light intensity, the vegetative growth of leaves and stems is accomplished quickly until the second half of April. Flowering started in mid-April and continued until late May. The seeds were in the milky state from the second half of May and with the increase of temperature in early June, they had doughy state and by the end of June, the seeds were fully ripe and began to fall. The phenology diagram in accordance with the embrothermic curve was shown in Fig 6.

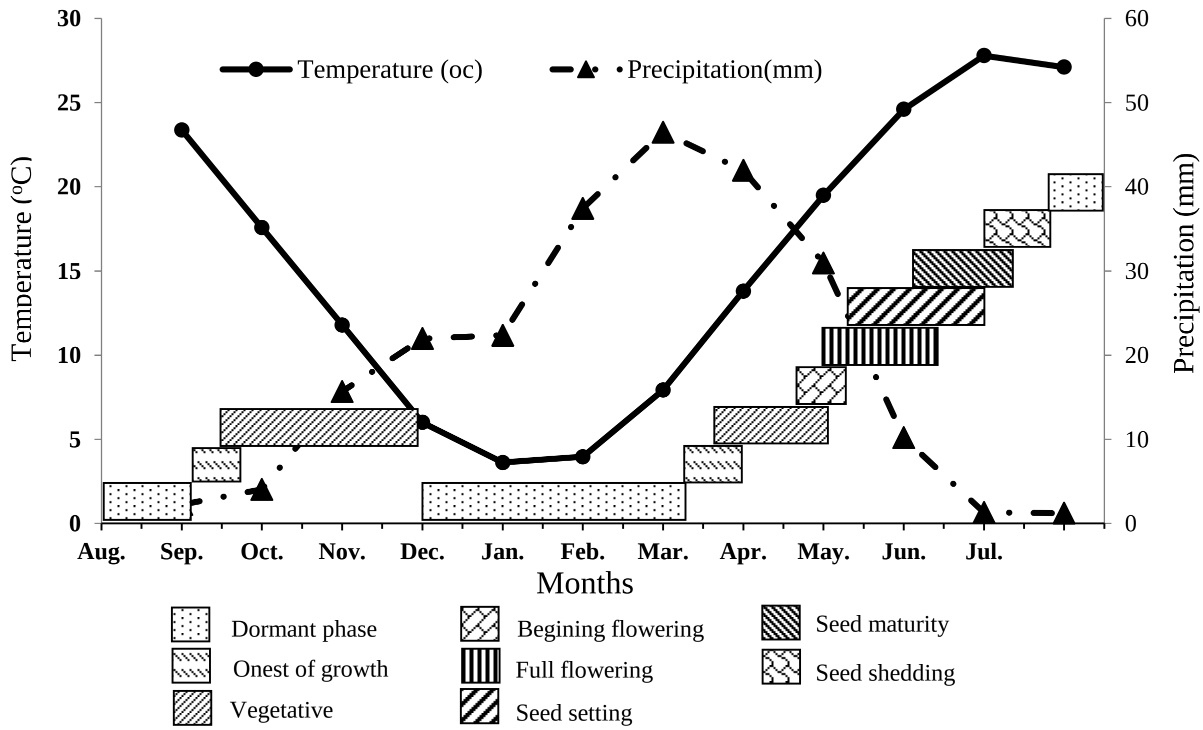

Fig 6. Embrothermic curve and Phenological diagram of *O. chorassanica* in studied habitats

Discussion

Taking into account the significance of *O. chorassanica*, appealing palatability and also its importance in soil conservation (Rahimi, 1999; Amirabadizadeh, 2009; Dashti *et al*., 2020), the ecological requirements of this species and its response to some environmental factors have been studied. The findings of CCA indicated that the percentage of lime, aspect, litter and slope by expressing 3.8, 3.3, 3.0 and 3.0% of the variance played significant roles in variations of the plant composition in habitats (Table 5). This study, furthermore, revealed that *Poa bulbosa*, *Gundelia tournefortii* and *Centaurea virgata* along with *O. chorassanica* were significant plant types in the region.

The revelations of the present study showed that out of 21 environmental variables, 6 variables were effective on the yield of *O. chorassanica*. The results of fitting the GAM to state its growth range under the influence of the studied variables showed that *O. chorassanica* is more dispersed on loamy to sandy soils. It has the highest yield in moderate amounts of sand (about 27 to 40%) and clay (about 40%). It appears that suitable drainage in these soils is one of the reasons that has led to further growth of this species in this type of soil, which is in conformity with the findings of Feizi *et al.* (2003) and Khalasi Ahvazi *et al.* (2011). Generally, soil texture has primary effect on the movement of water in the soil and is an important factor in nutrient availability and a factor in soil erosion potential (Alavi *et al.*, 2017). Soil sand percent as one of the factors of the soil texture plays an important role in the amount of water and elements available to plants as well as ventilation and rooting of the plant and finally in distribution of the vegetation (Wahba *et al.*, 1990). This finding is in conformity with the results of Rangel *et al.* (2006), Khalasi Ahvazi *et al.* (2011) and Esfanjani *et al.* (2017). The reaction of *O. chorassanica* to soil sand percent indicates a negative relationship between performance of this species and this factor. Therefore, with increasing the percentage of sand in the soil, the presence of *O. chorassanica* cover decreased and followed the monotonic decrease model. Conversely, with increasing the percentage of clay and lime, the frequency and percentage of vegetation of *O. chorassanica* increased and therefore followed the monotonic increase model. In confirmation of above results, Rahimi (1999) concluded that *O. chorassanica* grow easily in heavy and sedimentary soils with fine texture. Hossein Jafari *et al.* (2019) also showed that higher soil moisture and silt percent in *Ferula pseudalliacea* habitats may cause to increase vegetation parameters.

The reaction of this species to the variations in the OC and litter percent is up to 0.4 and 30%, respectively, and then, followed a downward trend. Therefore, the species response to these factors is unimodal. It appears that the rise in the litter percent to 30% leads to increase the abundance and canopy cover as a result of creating a suitable substrate for seeds and providing the necessary moisture to increase germination and establishment. Conversely, the decrease in the presence of *O. chorassanica* in areas with uncovered soil was consistent with the results of Vandenberghe *et al.* (2007). The canopy cover percent of *O. chorassanica* had a negative correlation with the bare soil percent but this response was statistically insignificant in the studied habitats. However, field observations and the reduction of the presence of this species in bare soils can be partly on account of reduced soil permeability, increased runoff, soil erosion and lack of seedlings establishment due to the special shape of seed pods (Rahimi, 1999). These would contribute in a significant manner to the lack of germination and establishment of the vegetation. The findings of the current study are consistent with the findings of Carcey Hincz and Irma (2011), Wassie *et al.* (2009) and Laris and Wardell (2006).

The growth range of *O. Chorassanica* in the Khorasan Razavi province was in the range of 750 to 1950 m; however, the plants were observed in the range of 1200 to 1350 m in the studied habitats. With rise in the altitude to more than 1350 m, the vegetation cover of this species diminished significantly. It appeared that *O. chorassanica* is closer to the dam water reservoir at lower altitudes; therefore, with respect to soil, air humidity and temperature, it has more favorable conditions for seed germination and growth. This has been confirmed by other researchers (Wang *et al.*, 2002; Balent and Stafford Smith, 1991). The reduced presence of *O. chorassanica* outside this range can be partly due to ecophysiological impediments such as reduction in growing season, reduced water holding capacity, low temperature and low production capacity of the ecosystem at higher altitudes as well as lack of rainfall, rise in temperature, and high level of evaporation at lower altitudes (Körner, 2007). The findings of this study indicated that increasing altitude more than 1300 m has adverse effect on the plant, and from then on, the downward trend followed. It appears that besides the altitude which negatively affects the distribution of *O. chorassanica* as a limiting factor, decreasing temperature and increasing light intensity play significant limiting roles. This result was in correspondence with those concluded by Rahimi (1999) showing a decrease in the presence of *O. chorassanica* at altitudes above 1300 m in the Firoozabad watershed. The results of Grime *et al.* (1987) also indicate that while increasing the altitude, other factors such as soil type or hydrological condition may independently change and significantly affect canopy cover.

The reaction of *O. chorassanica* to geographical direction followed the Unimodal model. Hence, the conditions for growth and presence of the species along the western and northern aspects are more desirable. Declined presence and yield of this species on the southern and southeastern slopes may be due to the ecophysiological constraints such as reduced soil moisture, high temperature and low ecosystem production capacity in these geographical aspects. Kolahi and Atri (2014) also showed that the presence of *Bromus tomentellus* is reduced in warm regions, especially in the southern and southwestern aspects. It seems that the northern aspect provides more suitable conditions for the presence of the plants as a result of lower radiation intensity and temperature as well as the increase of soil moisture. On the other hand, due to the physical dormancy caused by the hard seed coat, it can be asserted that in the northern slopes where the humidity is higher, washing the inhibitors in the seed pod can lead to breaking up the dormant seeds and increase the germination percent (Dashti, 2018). The findings similarly indicated that to increase the slope leads to the reduction in the cover percent and plant density. It seems that the reason is the decrease in the establishment of seeds of *O. chorassanica* and other species on steep slopes and also the increase in the percentage of bare soil as well as an increase in water erosion (Alavi *et al.*, 2017). In addition, after falling, the seeds remain on the soil surface due to their flat shape and large size and do not penetrate easily into the soil. Admittedly, in the moderate slopes, water porosity in the soil is increased; consequently, more seeds are exposed to the moisture, leading to the germination of the seeds and increased reproduction (Rahimi, 1999).

The results of phenological investigations of *O. chorassanica* revealed that the state of vegetative and reproductive growth stages in the first year of the plant growth and its comparison to the following years is somewhat slow and delayed. This can be due to the plant investment in the underground organs and establishment of the plant during the first year. Perennial plants have strong, deep roots and the plant regrowth begins with the gradual warming of the air from the first half of March. However, due to the cold weather, the vegetative growth of the plant is normally slow until early-April and gradually increases with increasing temperature. In confirmation of plant phenological results, Dashti (2018) by studying the cultivation methods and establishment of *O. chorassanica* in the second and third years of growth showed that the vegetative growth began in middle March, and then, the plants entered the flowering stage from late April to middle June and finally, seeds ripen gradually from late May to middle July.

Overall, the results showed that the proposed models for this species are validated only within the habitat conditions of the studied area, and in case, any attempt of generalization to other areas, it should be tested in other habitats. Although multivariate regressions such as the GAM can play a role in the expression of ecological nests of a particular species and this ecological range can include the interaction of biotic and abiotic factors; however, the relative role of living factors such as species competition as compared to non-living factors are not transparent and the issues of this nature needs further research and clarification.

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اثرات توپوگرافی و متغیرهای خاک بر حضور اسپرس خراسانی (*Onobrychis chorassanica* Bunge.) در مراتع کارده و کرتیان، مشهد، ایران

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چکیده. عوامل محیطی اثرات قابل ملاحظه‌ای در توزیع و عملکرد گونه‌های گیاهی دارند. بدین منظور پاسخ‌های گونه اسپرس خراسانی (*Onobrychis chorassanica* Bunge.) به برخی از عوامل محیطی در رویشگاه‌های استان خراسان رضوی (کارده و کرتیان) در طی سالهای ۱۳۹۷ تا ۱۳۹۹ مورد ارزیابی قرار گرفت. مدل‌جمعی تعمیم‌یافته (Generalized Additive Models) به‌منظور پاسخ این گونه به عوامل خاک و توپوگرافی استفاده شد. نتایج نشان دادند که گونه اسپرس خراسانی به برخی عوامل محیطی در رویشگاه خود، پاسخ معنی‌داری نشان داد. الگوی پاسخ این گونه در امتداد شیب درصد رس و آهک خاک، از مدل افزایشی (Monotonic increase)، پیروی نمود، لذا با افزایش مقادیر این عوامل، فراوانی و درصد پوشش گیاهی آن نیز بیشتر شد. برعکس، پاسخ این گونه در امتداد شیب، درصد شن خاک، از مدل کاهشی (Monotonic decrease) تبعیت نمود و با افزایش مقدار این عامل، حضور و درصد پوشش‌گیاهی، کاهش یافت. مطالعات خاکشناسی نشان داد که این گونه عمدتاً بر روی خاک‌های لومی تا لومی شنی پراکنش دارد. الگوی پاسخ گونه *O. chorassanica* در امتداد شیب، درصد کربن آلی و درصد لاشبرگ سطح خاک، از مدل زنگوله‌ای (Unimodal) پیروی کرده و حد بهینه رشد آن برای این عوامل، به‌ترتیب ۰/۴ درصد و ۳۰ درصد بود. عکس‌العمل این گیاه به جهت جغرافیایی نیز نشان داد که درصد فراوانی و پوشش‌گیاهی گونه مورد مطالعه در شیب‌های غربی و شمالی، بیشتر بوده و در شیب‌های جنوبی و جنوب شرقی بندرت پراکنش دارد. بررسی پاسخ گونه *O. Chorassanica* در امتداد شیب عوامل توپوگرافی و خاک، اطلاعات ارزشمندی برای تعیین نیازهای اکولوژیکی این گونه ارائه داد که می‌تواند در مدیریت پوشش‌گیاهی و عملیات اصلاح مراتع در مناطق مشابه، مورد توجه قرار گیرد.

کلمات کلیدی: اسپرس خراسانی، رسته‌بندی، عوامل اکولوژیک، مدل‌جمعی تعمیم‌یافته، منحنی پاسخ گونه