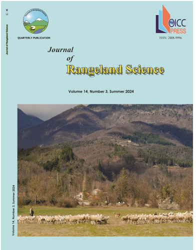

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Effects of soil and topography variables on canopy cover of *Dorema ammoniacum* D.Don in Soltan Mohammad Rangeland, Sabzevar, Iran

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Abstract:

Environmental factors have huge impact on yield and distribution of plant species. For this purpose, the response of *Dorema ammoniacum* (Apiaceae) canopy cover to some environmental factors was investigated in its natural habitat in south of Sabzevar, Iran in 2018-2020. Generalized Additive Model (GAM) was used to investigate the response of this species to soil and topography factors. The results showed that the edaphic and physiographic factors of the habitat had significant effects on the canopy size of *D. ammoniacum*. Environmental factors such as sand, litter, organic matter, lime, pH, N, P, K and altitude followed a monotonic increase model in response of canopy size. So, by increasing these factors, the canopy size of *D. ammoniacum* increased. In contrast, the response of canopy cover of this species to the gradient of clay, slope, EC, and SAR was a monotonic decrease model so that by increasing of these factors, the canopy percentage of *D. ammoniacum* was decreased. Results of the soil study showed that the plant is principally distributed on sandy loam and loamy sand soils. The reaction pattern of *D. ammoniacum* canopy cover in confronting with the gradient of silt, bare soil, and stone and gravel followed unimodal and the optimal level for them was 1%, 30% and 1%, respectively. Generally, investigation of *D. ammoniacum* canopy reaction to gradient of some environmental factors gave profitable data for characterizing the ecological demands of this plant. In other words, awareness of the impact of environmental factors on *D. ammoniacum* canopy cover can give range managers good information to recognize arable lands for cultivating this important species and recovering its destroyed habitats.

Keywords: *Dorema ammoniacum*; Environmental factors; GAM; Sabzevar

1. Introduction

Plant communities have changed over time due to the profit-seeking human intervention in nature, such as environmental destruction, overexploitation of natural resources, increase in greenhouse gases, etc. (Siahmansour et al., 2020; Pickett and White, 1985). Some studies have also shown that the biomass of Iran's forests and rangeland has decreased (Dashti et al., 2018; Heidari Sharifabad and Torknejad, 2000). Some factors such as overgrazing and off-season grazing lead to changes in plant composition while decreasing rangelands production (Dashti et al., 2020; Heidari Sharifabad and Torknejad, 2000).

Gum ammoniac (*Dorema ammoniacum* D.Don) from Apiaceae (with vernacular names such as Vosha and Kandal) is an endangered plant (Ghasemi Arian, 2016). *D. ammoniacum* is a hemicryptophyte, perennial and monocarpic plant with leaves consisting of a number of leaflets and yellow flowers; Schizocarp fruit, bulky roots, and 1 to 2 m tall stem with gum-containing tubes running throughout the stem and root (Mozaffarian, 2012). *D. ammoniacum* gum, which seeps naturally from the stem, is used in the pharmaceutical and industrial (Zargari, 1992; Mozaffarian, 2012; Amiri and Joharchi, 2016). The area of *D. ammoniacum* habitat in Iran is about 140,000 ha, in arid and semi-arid zones of

South Khorasan, Razavi Khorasan, Yazd, Kerman, Isfahan and Sistan and Baluchistan provinces, Iran (Ghasemi Arian, 2016).

D. ammoniacum is a rare and endangered species that grows only in Iran, Afghanistan, Pakistan and some parts of northern India (Irvani et al., 2010; Delnavazi et al., 2014). Precipitation and temperature data indicated that *D. ammoniacum* can resist a drop or rise in temperatures (Ghasemi Arian, 2016).

Understanding the ecological characteristics of plants and their response to environmental factors can give range managers good information about the conservation and their reproduction in similar areas (Gholami et al., 2002). The study of interactions between vegetation, climate, soil, and landforms agents has an important topic in ecological studies (Guisan and Zimmermann, 2000).

There are a number of ecological studies on the relationship between plant distribution and edaphic agents. Some statistical methods are used to analyze the abundance of species and others are used to study the agents affecting the dispersal of plant species and predict their suitable (Tomy et al., 2021; Bakkenes et al., 2002; Peterson, 2001; Berg et al., 2004; Robertson, 2003; Engler et al., 2004). Various mathematical models are used in studies related to the reaction of plants to environmental factors (Cardei et al., 2021). The Canonical correspondance analysis (CCA) method is used to investigate the reaction of plants to edaphic factors by relying on factors affecting the dispersal of species using the generalized incremental model (GAM) (Traoré et al., 2012). The GAM model, due to its exponential functions, enables it to develop a fine-tune nonlinear relationship between different variables (Guisan et al., 2002). The GAM model optimizes the prediction accuracy of the dependent variable and reduces the standard error by improving the robust analysis between the independent variables and the plant response to edaphic factors (Vaziri Nasab et al., 2013; Salehi et al., 2012; Mirdavoodi, 2013).

Literature review shows that the GAM model has been used in several rangeland and forest ecosystems in Iran. Mirdavoodi (2013) used the GAM model to investigate the response of some species to edaphic factors. He found that the reaction of some plants to excessive grazing causes an increase in soil bulk density. Another researcher reported that Achillea millefolium and Bromus tomentellus react differently to altitude. Also, the percentage of sand in the soil had a positive effect on the dispersal of B. tomentellus, but this factor does not have a favorable effect on the presence of yarrow (Achilla millefolium) (Heidari Sharifabad and Torknejad, 2000).

Considering that the *D. ammoniacum* is a rare and endanger species. Therefore, this study was conducted with the aim of investigating the response of *D. ammoniacum* canopy cover to soil and topographical variables using GAM model to determine the reaction of *D. ammoniacum* canopy area to environmental factors.

2. Materials and methods

To investigate some environmental factors affecting *D. ammoniacum* canopy cover percent, and some of its important companion plants such as *Artemisia sieberi, Convolvulus orientalis, Rosa persica, and Scariola orientalis* a habitat named Sultan Mohammad (75 km south of Sabzevar, located in the Shekasteh region in Razavi Khorasan province, Iran) was selected in 1918-2020 (Table 1).

Sampling of vegetation and some environmental factors was performed using systematic-random method (Dashti et al., 2021; Arzani and Abedi, 2015). For sampling of vegetation and soil, we divided the *D. ammoniacum* habitat into four slope classes (0-3%, 3-6%, 6-9%, and 9-12%) based on land slope. Then, in each of the slope classes, four transects

Table 1. Physiographic, climatic, soil and vegetation type characteristics of *D. ammoniacum* habitat in Khorasan Razavi province, Sabsevar, Iran.

Characteristics	Soltan Mohammad rangeland
Longitude	57°30′25″ to 57°30′30″ E
Latitude	35°42′15″ to 35°42′21″ N
Plant types	*Artemisia sieberi - Convolvulus orientalis*
Condition of plant type	Poor
Trend of Plant type	Downward
Density of *D. ammoniacum*	$0.19/m^2$
Chorotype	Irano-Tourani region
Ecological zone type	Steppe
Mean annual precipitation (mm)	166
Mean annual temperature (°C)	14.5
Climate*	Cold arid
Altitude (m. asl)	1400-1500
Mean slope (%)	1-12
Geographical aspects	Flat
Landform	Plain & hill
Soil texture	Sandy loam
Lithology	Quaternary

*: Climate conditions according to Emberger classification

Table 2. Average features of physiography, soil, and canopy cover in *D. ammoniacum* habitat.

Slope	Altitude	Aspect	Canopy cover	Total canopy cover	Litter	Gravel & rock	Bare soil
6.6%	1461 m	Non aspect	1.14%	32.1%	10.59%	10.62%	46.69%

with a length of 1000 m were randomly established (Mirdavoodi, 2013). In each transect, five plots with an area of 4 m^2 (minimal area by Releve method) were determined at an equal distance (200 m) from each other. Then, all vegetation data were measured at the flowering stage of *D. ammoniacum*. The measured data in each plot were canopy cover percent of *D. ammoniacum*, and other species and the amount (litter, gravel, rock) and bare soil percent. To investigate the effect of some ecological factors on canopy cover of *D. ammoniacum*, a soil sample was collected from each plot to the depth of the plant root (0-50 cm). The soil analysis was made including percentage of sand, silt, and clay (Bouyoucos-hydrometer), N (Kjeldahl method), P (Olsen method), K (Flame photometer), EC (electrical conductivity method), SAR (sodium absorption ratio), pH (electrometric method), organic carbon content- OC% (Walkley-Black method), and lime using titration method (Robertson et al., 1999). Among the factors related to physiological studies of *D. ammoniacum* habitat, aspect, slope and altitude were measured using GPS in each plot. To investigate the phenology of *D. ammoniacum*, we examined its vegetative and reproductive growth stages during three years (2018 to 2020). For this purpose, we selected 10 random *D. ammoniacum* plants inside each plot and recorded their phenological stages every 10 day (Dashti et al., 2021).

2.1 Data analysis

To investigate the relationship between environmental factors and the canopy cover percent of *D. ammoniacum*, we used the Detrended Correspondence Analysis (DCA) method as a nonlinear model and obtained the gradient length. Due to the length of the first axis in DCA was less than 3, we used the RDA[1] method. First, environmental factors were divided into three groups including soil (sand, silt, clay, pH, EC, lime, N, P, K, and organic matter), topography (altitude, and slope), rock outcrop (bare soil, rock, and gravel, and litter), then spatial correlation between sample plots was investigated (Borcard et al., 1992). In this study, the data analysis was performed using Canoco software version 4.5 (Ter Braak and Smilauer, 2002). For plotting the reaction of *D. ammoniacum* to environmental agents, we used the GAM model (Bakkenes et al., 2002; Godefroid and Koedam, 2004; Traoré et al., 2012). We used the Akaike Information Criterion (AIC) to rank the environmental variables affecting the *D. ammoniacum* canopy cover (Akaike, 1974). Therefore, the smaller the AIC value, the greater the variable effect on the canopy coverage percent; in other words, the proposed model was the most suitable model for fitting the response curve of the species. In this research, we investigate the relationships between the canopy cover percent of *D. ammoniacum* and environmental factors and drawing the Gaussian curves (Ardekani, 2009).

1. Redundancy analysis

3. Results

3.1 Vegetation attributes

The results showed that *Artemisia sieberi, Convolvulus orientalis, Rosa persica, Carex physodes*, and *D. ammoniacum* had the highest canopy cover percent with the values of 2.94, 2.86, 2.35, 2.22, 1.82, and 1.14 % respectively. In addition to *D. ammoniacum*, there were 39 plant species belonging to 38 genera from 23 families in the habitat. The average of soil factors along with some environmental features of the habitat is given in Table 2. The average percentage of *D. ammoniacum* canopy and some important species in the habitat is demonstrated in Figure 1.

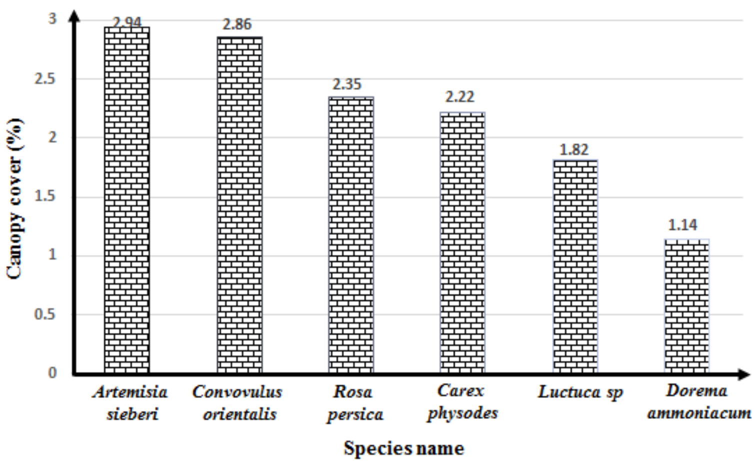

Figure 1. Mean canopy cover percentage of major species in Soltan Mohammad habitat.

3.2 Habitat characteristics

The results of physiography and climate studies showed that *D. ammoniacum* species grows in low slope and no aspect lands. Altitude changes for this species were obtained from 1420 to 1503 m above sea level. Other results related to soil analysis demonstrated that *D. ammoniacum* prefers sandy-loamy texture, alkaline pH, low organic matter, and low exchangeable sodium ratio (SAR) (Table 3).

3.3 Relationship between canopy cover and environmental factors

Using canonical classification model, 8 variables were selected from 18 primary variables. Selected variables among physiographic and soil factors are slope, clay, rock and gravel, litter, pH, lime, EC, and P, respectively (Table 4).
Data analysis showed that the total variance of vegetation in the RDA method was equal to 17799.4 which was equivalent to 33.8% of the total variance. In the RDA model, using spatial correlation and considering all selected variables as limiting variables, finally 8 variables including slope, clay, pH, EC, lime, litter, phosphorus and gravel were obtained among 16 main variables (Table 5). *D. ammoniacum's* ecological gradient showed that the first axis with an eigenvalue of 0.12, 12.4% and the second axis with an eigenvalue of 0.07, 19.7% can justify the vegetation variations. The results of plant species distribution related to ecological gradient in the first and second axes of the RDA model are presented in figure 2.
The interval of species from the coordinate axes demonstrates the power the relationship (Figure 2), in one hand, the greater the distance of the species from the center of the axes, the less environmental factors affect their distribution; on the other hand, the greater the correlation between environmental agents, the *D. ammoniacum* and other accompanying species have a stronger relationship with the characteristics of environmental factors. As well as the larger the length of vectors and the smaller their angles with the axes, the greater the correlation between environmental factors to the growth of *D. ammoniacum* and other plants of habitat.
The results of analysis of variables in the GAM model indicated that more of environmental factors had a significant effect on the canopy cover percent of *D. ammoniacum* (Table 5).
The response of *D. ammoniacum* canopy cover percent in relation to the environmental variables (sand, litter, organic matter, lime, pH, N, P, K, and Altitude), conformed the monotonic increase model and canopy cover percent of *D. ammoniacum* increased with increasing these factors (Figure 3), But it decreased with the increase of some gradients such as clay, slope, EC and SAR (Figure 4).
The canopy cover percent of *D. ammoniacum* in relation to the factors of silt, stone & gravel and bare soil showed that the response of *D. ammoniacum* to these agents was

Table 3. Minimum and maximum and mean values of environmental factors in *D. ammoniacum* habitat.

Environmental factors	Min.	Max.	Mean
Sand (%)	51.0	83.0	69.0
Silt (%)	4.0	34.0	19.0
Clay (%)	4.0	18.0	12.0
pH	7.9	8.3	8.0
EC	0.50	0.88	0.81
SAR	0.35	0.60	0.47
Lime (%)	14.0	34.0	24.0
N (%)	0.01	0.07	0.03
P (%)	1.8	8.0	5.0
K (ppm)	190	450	307
OM (%)	0.01	0.27	0.41
Litter (%)	7.0	15.0	10.6
Rock & ravel (%)	7.0	25.0	15.6
Bare soil (%)	31.4	56.9	41.6
Altitude (m)	1420	1503	1462
Slope (%)	1.0	12.5	6.6
Precipitation (mm)	0.6	33.8	166.0
Temperature (°C)	-5.0	34.0	15.0

Table 4. The major eight environmental factors effective in *D. ammoniacum* growth.

Environmental factors	Variance	F values
Slope	11.6	7.6**
Clay	4.9	3.3**
pH	3.8	2.7**
EC	2.9	2.1**
$CaCo_3$	3.2	2.3**
Litter	3.1	2.3**
P	2.3	71.7*
Rock & gravel	2.1	1.6*

*,**: are significant level at 0.05 and 0.01, respectively

Table 5. The level of Significant of environmental variables in the GAM model.

Environmental factors	F	Akaike Information Criterion (AIC)
Sand (%)	8.2**	72.32
Silt (%)	3.0*	85.35
Clay (%)	10.7**	14.79
pH	10.8**	67.06
EC (dS/m)	9.5**	69.80
SAR	9.2**	70.20
$CaCO_3$ (%)	9.6**	69.23
N (%)	22.8**	49.40
P (%)	9.4**	69.72
K (ppm)	10.0**	68.44
OM (%)	10.5**	67.83
Slope (%)	9.2**	70.45
Altitude (m)	10.7**	67.87
Litter (%)	7.5**	73.76
Bare soil (%)	31.1*	41.49
Stone & gravel (%)	2.2^{ns}	88.73

*,**: significant at $P< 0.05$ and $P< 0.01$ probability level, ns: not significant

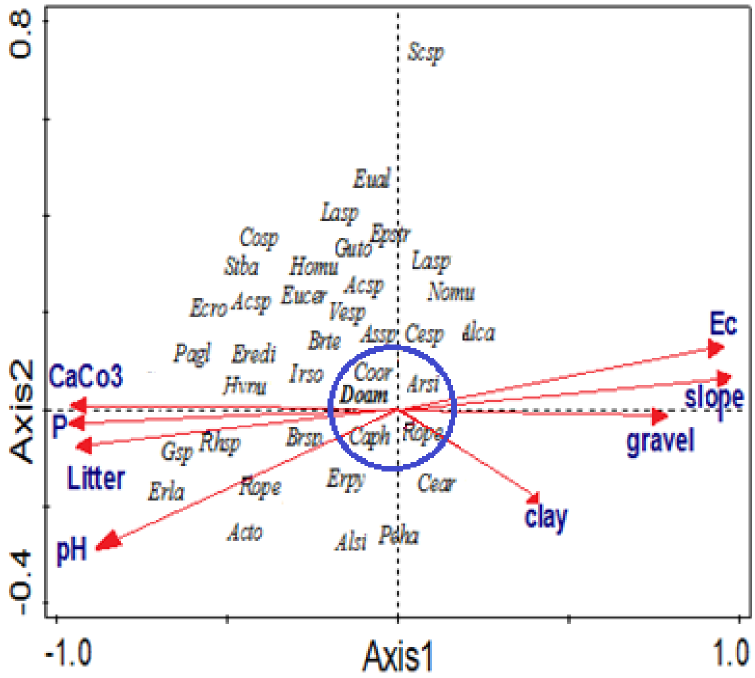

Figure 2. Plant species distribution related to ecological gradients.

unimodal. According to Figures. 4j and 4p, with increasing the amount of silt up to 12% and gravel up to 10%, the *D. ammoniacum* canopy increased; then, with further increase of these factors, the *D. ammoniacum* canopy decreased. In contrast, by increasing the bare soil up to 45%, the canopy decreased, and after that with increasing this factor, the canopy increased (Figure 4m).

3.4 Phenology of *D. ammoniacum*

Seeds of *D. ammoniacum* had a physiological dormancy; cold stratification is useful in germination. *D. ammoniacum* is a hemicryptophyte species; therefore, during the autumn season, it lost its aerial part and started (Figure 5). The phenological diagram with the embrothermic curve is shown in figure 6. According to phenological diagram, dormancy starts in Late September and continues until the early of March. Then, with a gradual increase in temperature from mid-March, the bud of *D. ammoniacum* emerges from the collar surface and leaves begin to grow and vegetative growth continues until early June. For older individuals of plants that are in their reproductive age, with the growth and development of rosette leaves, flowering stem emerges in them and from late May to early July, the flowers gradually appear on their branches (Figure 5).

Then, during July, the flowers gradually turn into milky seeds, after which mature seeds gradually form in August. As the air temperature increases, the leaves gradually dry and finally, the ripe seeds are dispersed by the end of September. Individuals of *D. ammoniacum*, who are not in reproductive stage, enter the dormancy period after the leaves dry, and their dormancy continued until the beginning of March.

4. Discussion

Considering the medicinal, industrial and fodder importance of *D. ammoniacum*, and also, its importance in soil conservation (Ghasemi Arian, 2016), the ecological requirements of this species and its response to some environmental factors have been studied. The results of RDA demonstrated that among 16 environmental variables, the amounts of sand, clay, litter, organic matter, lime, pH, N, P, K, SAR, slope, and altitude had significant effects on variations of the *D. ammoniacum* canopy cover. In this regard, Ghasemi Arian (2016) evaluated the influence of environmental, physiographic and climatic variables on the density of *D. ammoniacum* species in a neural network analysis. Also, Zare et al. (2021) reported that the three factors of slope, amount of lime and clay had an important role in the distribution of *D. ammoniacum* species. The present study revealed that Artemisia sieberi, Convolvulus orientalis, Rosa persica, Carex physodes along with *D. ammoniacum* are important species in this study area which is consistent with the researchers of Rajaei and Mohamadi (2012). The results of GAM fitting in relation to the effect of edaphic variables on the percentage of canopy cover showed that *D. ammoniacum* has more distribution on sandy loam to loamy sand soils. Similarly, Shafiee-Nick and Ejtehadi (2014) in a study on the autecological of Dorema kopetdaghense pimenov in Khorasan Razavi province, Iran found that this species grows in the loamy-sandy soil.

It seems that the proper drainage in these soils is one of the reasons that had improved canopy percent of *D. ammoniacum* plant in this soil type, which agrees with literature (Khalasi Ahvazi et al., 2011; Feizi et al., 2003).

Overall, Soil texture has an important role in infiltration, nutrient retention and preventing soil erosion (Alavi et al., 2017). The percentage of sand plays an important role in the

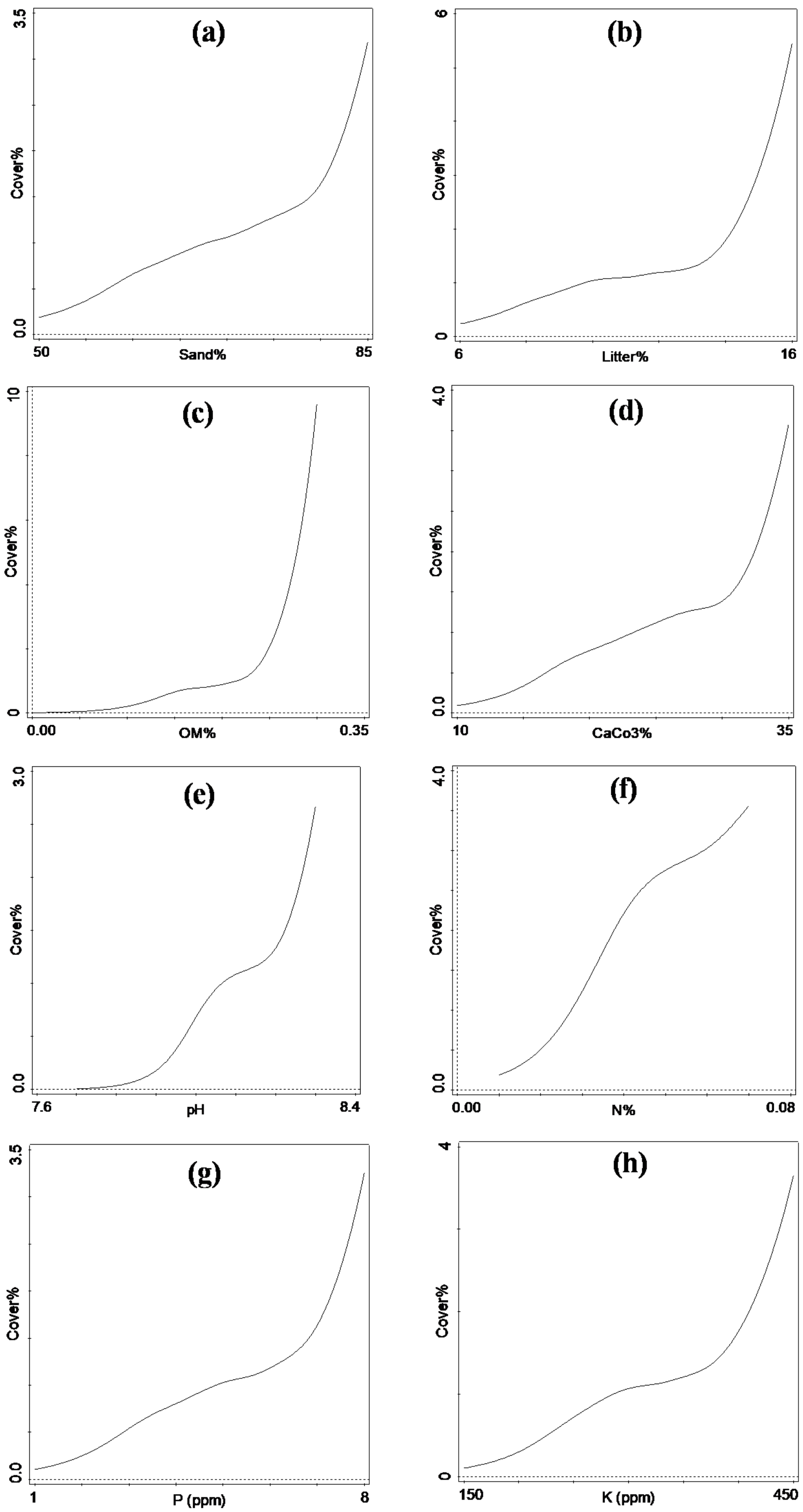

Figure 3. *D. ammoniacum* responses to Sand, Litter, OM, Clay, pH, N, P, and K.

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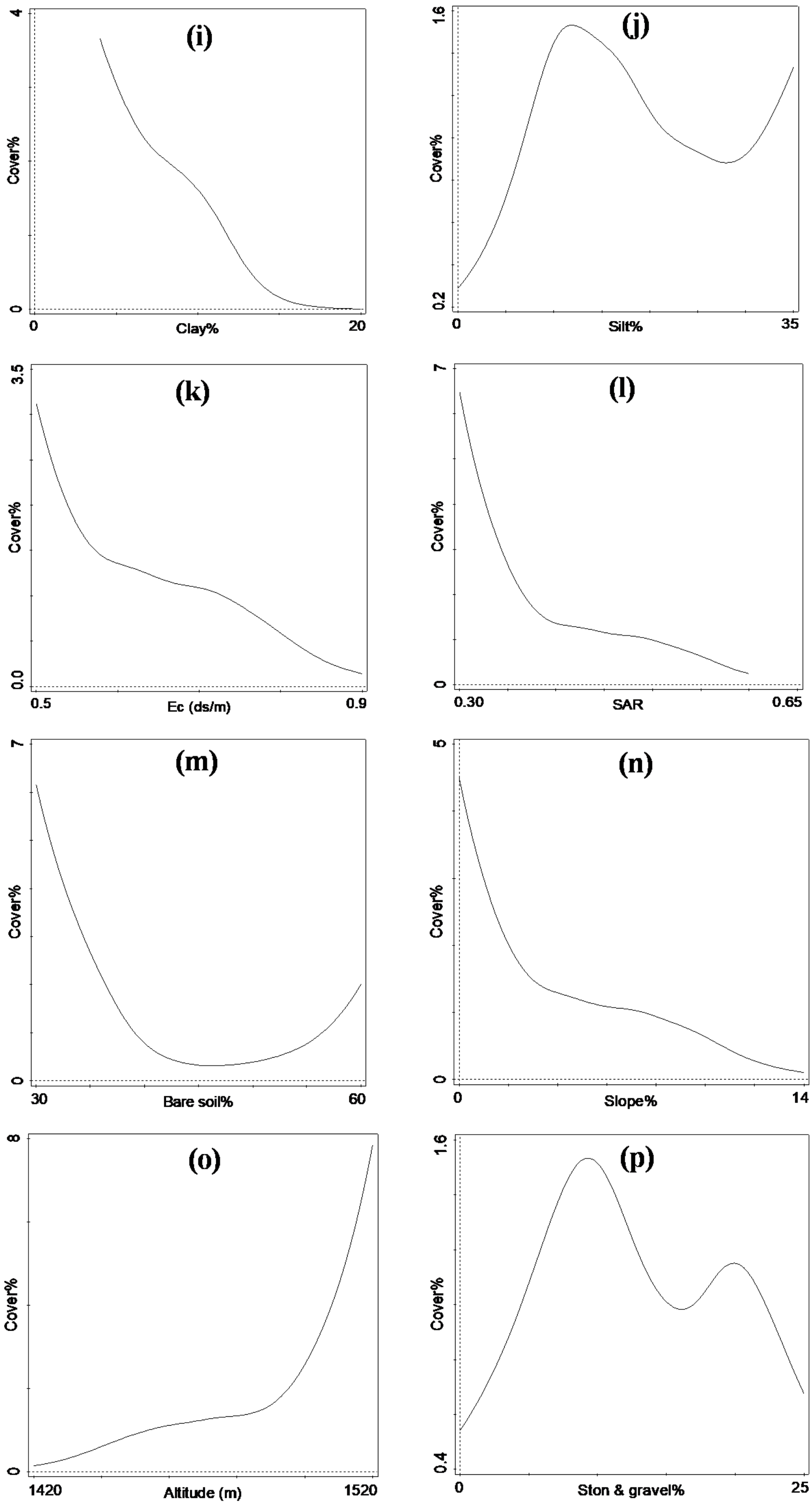

Figure 4. *D. ammoniacum* responses to Sand, Litter, OM, Clay, pH, N, P, and K, Clay, Silt, EC, SAR, Bare soil, Slope, Altitude, Stone & Gravel.

Figure 5. A view of field study (*Dorema ammoniacum* is in flowering stage).

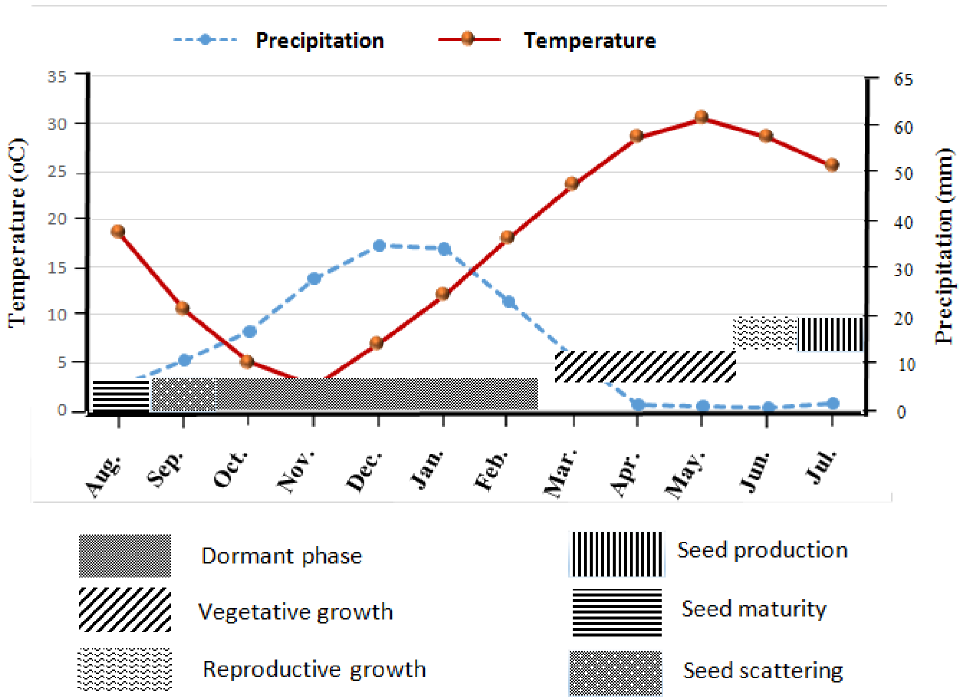

Figure 6. Embrothermic and phenological diagram of *D. ammoniacum*.

amount of porosity and soil aeration, as well as in plant rooting and vegetation distribution (Wahba et al., 1990; Rangel et al., 2006; Khalasi Ahvazi et al., 2011; Esfanjani et al., 2017).

In present study, the response of *D. ammoniacum* canopy cover to EC, SAR, clay soil and slope was negative, and its response to pH, N, P, K, lime, organic matter, litter and altitude was positive, indicating that by increasing pH, N, P, K, lime, organic matter, litter and altitude canopy cover increased and followed the monotonic increase model. In line with our results, Ghasemi Arian (2016) reported that *D. ammoniacum* is well adapted to soils having high pH, lime, and potassium. Our results showed that *D. ammoniacum* species grows in lower slopes so that the average slope in its habitat was 6.6%. Ghasemi Arian (1994) also suggested that *D. ammoniacum* canopy percent in lands having a gentle slope (2% to 5%) and their lime contents are about 17% more than lands having 12% slope and low lime. The results of this study showed that the percentage of *D. ammoniacum* canopy had a negative correlation with bare soil. However, it seems in the area of its habitat where the soil surface was rocky and sandy, the canopy reduction was partly due to soil erosion and lack of soil organic matter. The growth range of *D. ammoniacum* in this habitat was in the range of 1440 m to 1500 m and lands with a slope of 5% to 12%. Therefore, with the rise in altitude, the canopy cover of this species significantly increased, but with increasing slope, the canopy cover decreased (Figure 4). Study of vegetative growth stage in *D. ammoniacum* showed that this phase is slower in the first year of plant life than older individuals. This may be due to the strengthening of the roots by storing nutrients in the initial establishment of the plant. Older individuals had roots with a diameter of more than 10 cm and a depth of more than 30 cm, and the length of their sub-roots extends up to 3 m below the ground. (Ghasemi Arian, 2016). *D. ammoniacum* individuals over one year of age begin their vegetative growth in the first half of February (Figure 6). The vegetative growth rate is slow at first, but with increasing air temperature, it is going up from late-March. In this regard, Gholami and Faravani (2015) after planting and monitoring the *D. ammoniacum* in Ghaen region (Khorasan Razavi province, Iran) stated that the beginning of vegetative growth of *D. ammoniacum* is in early February, the flowering stage (for older individuals) in mid-April, seed production in mid-May, seed maturity in mid-June and seed dispersal in August. However, its ecological needs are almost the same in different habitats, but it is important to note that the models obtained are related to the habitat of Sultan Mohammad (Khorasan Razavi province, Iran) and it is better do not be generalized to other habitats. Although nonlinear models such as GAM are able to accurately calculate the interactions between living and non-living things in ecosystems, but to show the relationship between inter and intra interspecific interactions (symbiosis) such as competition, synergy, etc., it is requiring detailed field and laboratory studies.

5. Conclusion

Generally, in this study, we could obtain the important environmental factors on the size of *D. ammoniacum* canopy cover in one of its habitats. Also, based on the results of this research, it is necessary to consider some important environmental factors such as soil texture, litter, organic matter, the amount of lime and altitude up to 1520 m for the propagation of *D. ammoniacum*. Due to the fact that the physiological zero of *D. ammoniacum* is lower compared to other species in the region; therefore, in March when the soil is cold, it starts growing earlier than other plants, so to preserve its survival, it is necessary to protect it from premature grazing. These results can be used to find areas suitable for cultivation as well as to restore the destroyed habitats of this valuable plant in Iran.

Authors Contributions
All authors have contributed equally to prepare the paper.

Availability of Data and Materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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