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Applying Multivariate Factor Analysis Approach in Land Suitability Evaluation for Medicinal-Ornamental Plant Damask Rose in Northeast of Iran

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Abstract

Lack of knowledge of vital factors in the production and cultivation of plants in unsuitable areas can increase the use of chemical fertilizers to prevent a reduction in plant yield. In the present study, the factor analysis (FA) by principal component analysis (PCA) method as multivariate statistical was applied to evaluate the land suitability zonation of 36700 points for damask rose plantation in North Khorasan Province, NE Iran. For this purpose, the extracted 16 variables were processed, resulting in four factors that explain about 90% of the total variance. The explained variances of those factors are varied from 28.573 to 8.855% for factors 1 and 4 after the Varimax rotation, respectively. The zonation map of land suitability revealed that 2.61% (665.6 km^2) of the surface area was highly suitable, 95.78% (24410.47 km^2) was moderately suitable and 1.61% (409.74 km^2) of the region was marginally suitable for damask rose production. The geographical distribution revealed that the points with very high suitability are laid in the Western, middle, and Eastern parts of the study area, while the mid part of the study area and some scattered parts in the East, Northeast, and Northwest exhibited moderate suitability for damask rose. The most important limiting factors for the damask rose plantation in the study area were climatic factors including mean temperature during the growing cycle, mean temperature during the germination, and mean temperature during the flowering.

Keywords: Damask rose, Factor analysis, GIS, Land suitability, Multivariate statistical.

INTRODUCTION

Damask rose (*Rosa damascena* Mill.) is widely founded in temperate and subtropical regions of the Northern hemisphere and involves over 190 shrub species (Cairns *et al.,* 2000; Bruneau *et al.,* 2007). Roses are used for culinary, fragrance, and ornamental purposes, and besides these effects, several antioxidants, antitussive, anti-HIV, antibacterial, hypnotic, and anti-diabetic properties are reported for pharmacological properties of this plant (Hongratana worakit, 1994; Boskabady *et al.,* 2011). It is known that damask rose has known a prominent species within the perfume industry made by petals (Kiani *et al.,* 2009). Right now, this plant is cultivated in several parts of Iran including North Khorasan province. This part of Iran (North East) provides suitable conditions for the cultivation of *Rosa*. However, despite the popularity of *Rosa*, less attention has been paid to considering the suitability assessment in *Rosa* cultivation. Recent progress in the field of Precision Agriculture using remote sensing (RS) data and Geographical Information Systems (GIS) helps in due to the specific position of damask rose in the national economy, the feasibility study of damask rose estimating land suitability through multi-criteria decision making (MCDA) methods such as factor analysis.

Land evaluation (FAO, 1976) is defined as "the process of assessment of land performance when used for specific purposes". The FAO Land Evaluation Framework (1976) has been the primary procedure employed worldwide to address local, regional, and national land-use planning. Land suitability evaluation examines the degree of land suitability for a selected utilization type (Sys *et al.,* 1991) and an outline method or estimation of potential land productivity (Rossiter, 1996). Bagherzadeh *et al.* (2021) assessed the qualitative land suitability evaluation for the growth of ash and spruce in Mashhad plain, Northeast Iran. Mansouri Daneshvar *et al.* (2013) performed an agrometeorological suitability zonation in Khorasan Razavi, Northeast Iran. For this purpose, land suitability classification was carried out using the parametric method and therefore the consequent land suitability maps were prepared for irrigated farming. Land evaluation is the process of predicting the utilization potential of land based on its attributes. The methodology adopted, based on FAO guidelines, for land evaluation involves most aspects of climatic, soil requirements, and land terrains (including soil physical properties, soil fertility, and chemical properties, soil salinity and alkalinity, topography, erosion hazard, and wetness) for every crop (Sys *et al.,* 1991; Sys *et al.,* 1993).

Factor analysis has been extensively used in studies of agroclimatic zonations by certain meteorological parameters measured in a network of stations or grid points for a long period (Bartzokas and Metaxas, 1995). The factor analysis was first applied for climatic classification by Steiner (1965) in the USA. McBoyle (1973) used the technique to obtain the climatic regions of Australia. Russell and Moore (1976) used this approach in their studies on the climate survey of South Africa and Australia. Ahmed (1997) used the factor analysis technique and found it satisfactory, as it produces richer regions and shows clear climate variations within Saudi Arabia. In recent years, parallel with the growth of the quantitative revolution in geography, this type of classification has become widespread (Murray, 1999; Yussof *et al.,* 2004). In Iran, some studies have been utilizing factors to classify climate conditions. For instance, Alijani *et al.* (2008) developed a climate model for Iran based on spatial regionalization of factor analysis and cluster classification. The present study aims to apply factor analysis (FA) by principal component analysis method as a multivariate statistical approach to estimate the land suitability zonation for damask rose plantation in North Khorasan Province, Northeast Iran.

MATERIALS AND METHODS

The geographical position of the study area

The study region with a total surface area of 25485.81 km^2 lies between 55°52′–58°20′ Eastern longitude and 36°34′–38°17′ Northern latitude in North Khorasan Province, NE Iran (Fig. 1). The climatic features of the study area are mostly semi-arid with a long-term mean annual precipitation of 262.3 mm. The topographical elevation varies between 270 m a.s.l in the Atrak

River in the Northwest and 3035 m a.s.l in the center and Eastern parts of the study area (Fig. 2). The mean annual temperature ranges from 19.1 to 28.4 °C with an increasing trend from East to West. The highest slope gradients belong to heights from East to West of the study area and vary between 0.0 to 46.3 degrees in flatlands and mountainous regions, respectively (Fig. 3).

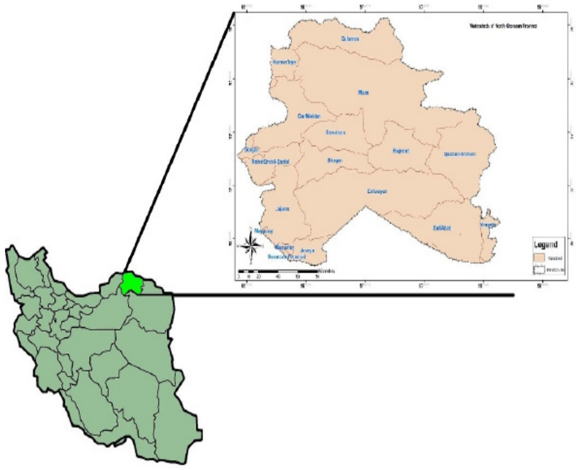

Fig. 1. The geographical position of the study area.

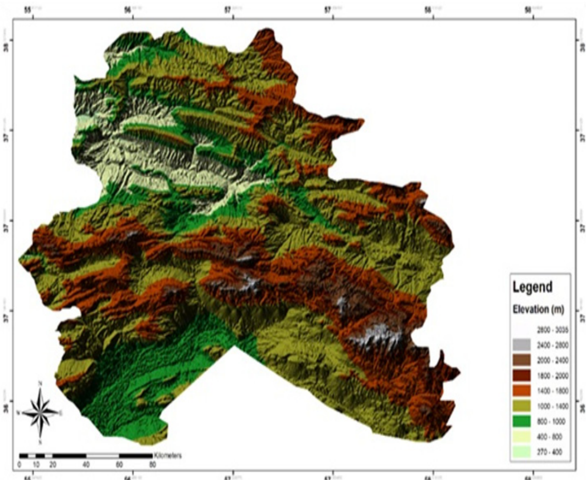

Fig. 2. Topography and elevation map of the study area.

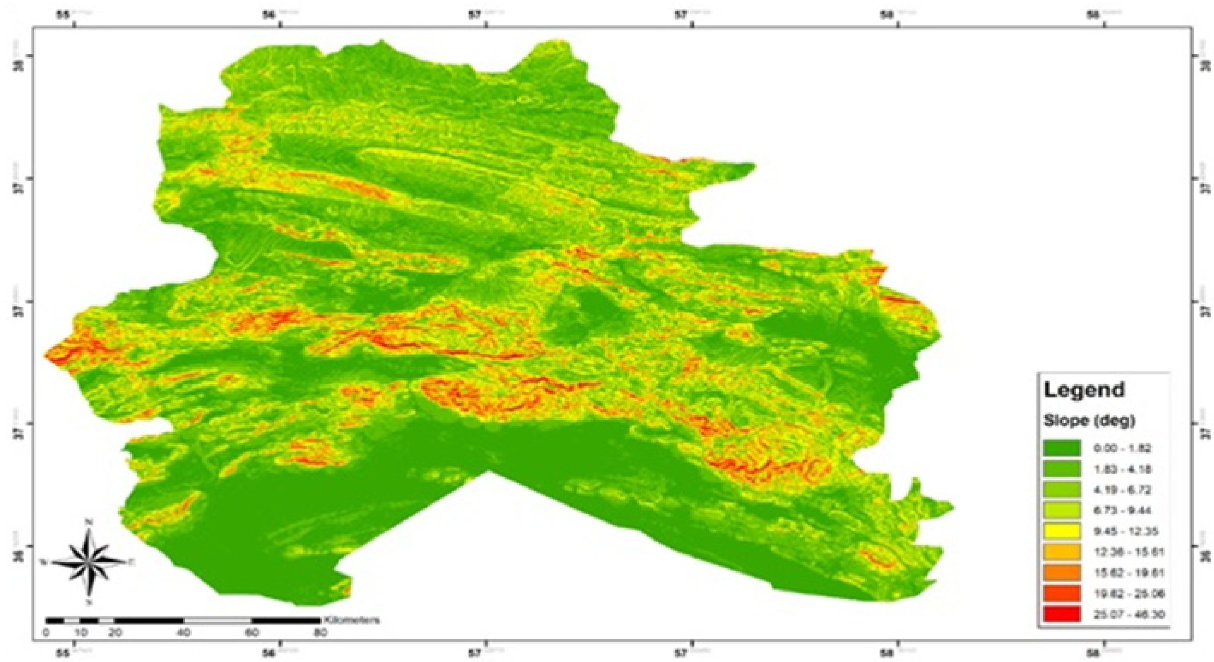

Fig. 3. Slope degree of North Khorasan province.

Application of factor analysis

Many climates and soil chemical-physical and fertility factors may affect land suitability evaluation. In practice, principal and representative factors are usually applied to simplify and reduce all factor information (Ouyang, 2005). Applying the multivariate statistical approaches including FA reduced the variables to a couple of factors. Factor analysis is understood as a strong method for drawing major factors influencing the observed data. The main reason to hold out a factor analysis is data reduction to determine the quantity and character of linearly independent variables (factors) which might precisely express the interdependence of the initial variables. Factor analysis as a generic term includes principal component analysis (PCA) or empirical orthogonal function analyses (Bukantis, 2002) that are functionally very similar and are used for the same purpose of data reduction (Gorsuch, 1983; Loehlin, 1992). Factor analysis was performed in a sequence with the following major steps: (1) Selecting and coordinating the variables after land suitability purposes, (2) Computing the matrix of correlations among the variables, and (3) Extracting and rotating the factors by the Varimax method, (4) Interpreting the rotated factor matrix to get the loading values.

Data collection

Due to climatic data shortage in and around the study area, climatic factors were extracted from WorldClim (ver.2) in spatial resolutions of 30 seconds (~1km^2). The most important implication in estimating soil physical and chemical properties within the study area was reliable soil data; hence, we used soil data from SoilGrids 250 m (ver.2.0), which uses digital soil mapping of worldwide collections of soil profiles. It is a set of soil properties including soil physical and chemical attributes in 36700 points up to 100 cm soil depth or to a restricted layer. The terrain values including elevation, slope, and aspect were estimated from the 30 m DEM of the study area. The shapefiles of flood hazard and erosion risk in Iran were used and processed by ArcGIS (ver.10.7) to point out plantation limitations within the study area.

Land data analysis

The terrain and soil suitability were evaluated by considering the soil requirements of the damask rose in terms of growth and biomass production. The values of climate, soil, and terrain characteristics of the region included mean annual temperature, mean temperature during the dormancy, mean temperature during the germination, and mean temperature during the flowering, annual precipitation, slope, elevation, soil depth, coarse fragments, pH, $CaCo_3$, calcium carbonate content (CEC), organic carbon (OC), EC, and ESP (Table 1). The next step was a land evaluation by comparing land qualities/characteristics with the damask rose requirements and classifying land suitability for each species (Table 2).

Table 1. The statistical description of climate and soil characteristics in North Khorasan province.

	Unit	Min	Max	Average	STD	CV
Mean annual temp.	◦C	22.11	31.45	27.33	9.33	0.08
Mean temp. during the dormancy	◦C	6.94	18.13	13.18	11.19	0.20
Mean temp. during the germination	◦C	9.67	20.20	15.63	10.53	0.16
Mean temp. during the flowering	◦C	23.02	31.63	27.90	8.61	0.08
Annual precipitation	mm	219.83	273.86	250.30	54.04	0.05
Slope	%	0.01	38.14	5.12	38.13	0.91
Elevation	m	271.02	2979.3	1279.5	2708.3	0.32
Soil depth	cm	0.00	149.9	20.12	149.9	0.91
Coarse fragment	%	0.00	46.00	15.93	46.00	0.37
pH	_	6.70	8.30	7.95	1.60	0.02
$CaCO_3$	%	0.30	40.00	17.71	39.70	0.45
CEC	$Cmol^+/kg$	8.00	41.00	18.01	33.00	0.18
OC	%	0.00	4.50	0.37	4.50	0.58
EC_e	dS/m	0.00	4.00	0.55	4.00	0.99
ESP	%	1.00	33.00	9.60	32.00	1.09

Table 2. Terrain, soil, and climate requirement for damask rose (*Rosa × damascene*) plantation.

Climatic characteristics	**Unit**	**S_1**	**S_2**	**S_3**	**N**
		100-85	**85-60**	**60-40**	**40-0**
Mean annual temperature	◦C	>15	15-10	10-5	<5
Mean temperature during the dormancy stage (January, February)	◦C	-4 -2	-2-0	0-2	>2
Mean temperature during the germination stage (April)	◦C	20-15	15-10	10-5	<5
Mean temperature during the flowering stage (May, June)	◦C	20-18	18-16	16-12	<12
Annual precipitation	mm	>250	250-150	150-100	<100
Slope	%	0-20	20-40	40-60	>60
Elevation	m	2300-1900	1900-1200	1200-850	<850
Soil depth	cm	>100	100-50	50-30	<30
Coarse fragment	%	0-15	15-35	35-55	>55
Soil texture		L, SL, SiL	SCL, SC SiCL, CL	SiC, Si	SL, S, C
pH		6.5-7.5	7.5-8.0	8.0-8.7	>8.7
		6.5-6.0	6.0-5.5	5.5-4.9	<4.9
$CaCO_3$	%	0-5	5-10	10-15	>15
CEC	$Cmol^+/kg$	>16	16-12	12-8	<8
OC	%	2.4-1	1-0.8	0.8-0.5	<0.5
EC_e	dS/m	0-2	2-4	4-7	>7
ESP	%	0-8	8-15	15-20	>20

The parametric approach in land suitability evaluation

In the present study, the specific soil and climate requirements for damask rose were determined based on the adaptation and abundance of damask rose in natural habitats (Table 2). For the parametric approach, we used the "Framework for Land Evaluation" (FAO, 1976) and "Land Evaluation for Forestry" (FAO, 1984), which distinguishes the climatic conditions and land features such as topography, wetness, soil physical and chemical properties, erosion hazard, soil salinity and alkalinity for each specific tree. The parametric approach determines the land suitability index and class based on the limitation rate of climate and land qualities/characteristics requirements for damask rose ranging from 0 to 100 (Table 2). The limitation value for every limiting factor is calculated by the subsequent linear interpolation equation:

$$y = a + \frac{(b-a)(x-c)}{(d-c)}$$

where, if the observed value of each land quality/characteristic (x) falls into the interval [a, b] in each limitation class it gets a limitation rate (y) that falls into the interval [c, d] which are the lower and upper threshold values defined for that limitation class.

Data preparation

In the statistical processing of data through factor analysis by principal component analysis (PCA), the extracted 16 variables were reduced into 4 factors consistent with Varimax rotation, which maximizes the total variance of the squared loading variables (>90 %) with eigenvalues greater than 1 (Table 3). The advantage of a Varimax rotation is that it keeps the principal components uncorrelated (Jolliffe, 1986; Paschalidou *et al*., 2009; Wilks, 2011).

The scree plot of 16 analyzed components by defined eigenvalues is shown in Fig. 4. In factor analysis, the factor scores for every case were calculated by the Varimax rotation with Kaiser normalization, principal component analysis method, and rotation convergence in 10 iterations (Table 4). The final step of the multivariate approach is to protect the data on the rotated significant factors.

Table 3. Total variance explained.

Components	Initial eigenvalues			Extraction sums of squared loading			Rotation sums of squared loading		
	Total	Variance (%)	Cumulative (%)	Total	Variance (%)	Cumulative (%)	Total	Variance (%)	Cumulative (%)
1	6.164	38.526	38.526	6.164	38.526	38.526	4.572	28.573	28.573
2	2.679	16.742	55.269	2.679	16.742	55.269	3.614	22.588	51.162
3	1.586	9.912	65.181	1.586	9.912	65.181	1.966	12.289	63.450
4	1.140	7.125	72.306	1.140	7.125	72.306	1.417	8.855	72.306
5	0.905	5.653	77.959						
6	0.804	5.025	82.984						
7	0.677	4.230	87.214						
8	0.639	3.994	91.208						
9	0.469	2.933	94.141						
10	0.341	2.130	96.271						
11	0.315	1.971	98.242						
12	0.197	1.228	99.471						
13	0.039	0.245	99.715						
14	0.026	0.161	99.876						
15	0.019	0.120	99.996						
16	0.001	0.004	100.00						

Table 4. Rotated component matrix.

	Component				Weight
	1	2	3	4	
Mean temp. growing	0.970				0.0988
Mean temp. germination	0.962				0.0980
Mean temp. flowering	0.956				0.0974
Soil depth		0.905			0.0922
OC		0.720			0.0733
pH		0.635			0.0647
Elevation		0.435			0.0443
Annual precipitation			0.837		0.0852
ESP			0.794		0.0809
$CaCO_3$			0.682		0.0694
Soil texture				0.740	0.0753
CEC				0.672	0.0684
ECe				0.513	0.0522

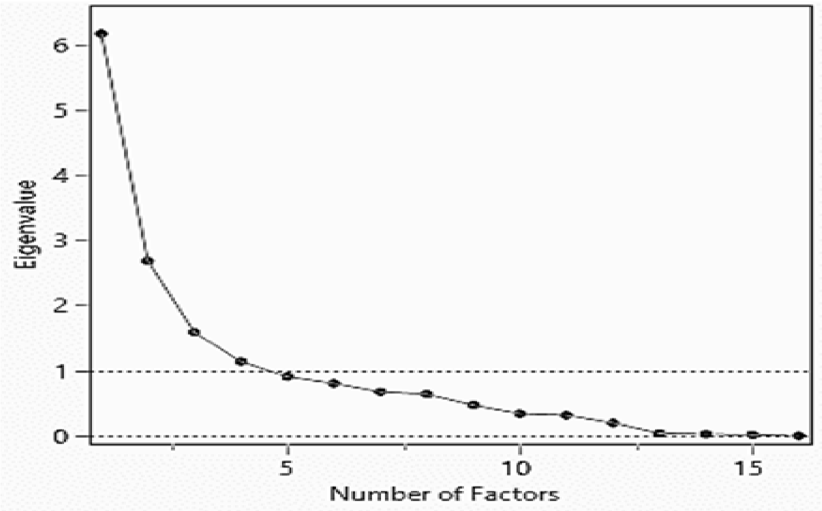

Fig. 4. The scree plot of 16 analyzed components by defined eigenvalues.

The zonation map of the land suitability

The geostatistical interpolating procedure of inverse distance weighting in ArcGIS was utilized for estimating the variable values in the studied area.

RESULTS AND DISCUSSION

Our results indicated that four factors explain about 90% of the total variance with eigenvalues greater than 1 (Table 4, Fig. 4). The explained variances of these factors varied from 28.573 to 8.855 % for factors 1 and 4 after the Varimax rotation, respectively (Table 3). Also, each factor showed different loadings for each variable (Table 4). Factor 1 with 3 variables comprised climatic characteristics including mean temperature during the growing cycle, mean temperature during the germination stage and mean temperature during the flowering stage which explained 28.573 % of the total variance with an eigenvalue of 4.572. Factor 2 with 4 variables including soil depth, OC, pH, and elevation which explained 22.588 % of the total variance with an eigenvalue of 3.614. Factor 3 with 3 variables including annual precipitation, ESP, and $CaCO_3$ which explained 12.289 % of the total variance with an eigenvalue of 1.966. Factor 4 with 3 variables including soil texture, CEC, and EC_e which explained 8.855 % of the total variance with an eigenvalue of 1.417. The distributions of components in each factor were reasonably homogenized from 1 to 4. According to Lavalle *et al*. (2009), there is a decent relationship between local climatic conditions and therefore the growth requirements of the plant species. Our results are consistent with the findings of Gholizadeh *et al*. (2020), who explained that natural climate factors such as air temperature and precipitation revealed the main indicators of plantation development.

Lavalle *et al*. (2009) showed that the plant species have different responses to the interaction between climatic factors, soil characteristics, and land qualities in the region. This observation illuminates the fact that climate factors have significant roles in plant growth and development. The land suitability classes for damask rose were categorized into a highly suitable class of S_1, a moderate suitable class of S_2, and a marginally suitable S_3. The zonation map of land suitability revealed that 2.61% (665.6 km^2) of the surface area was highly suitable, 95.78% (24410.47 km^2) was moderately suitable and 1.61% (409.74 km^2) of the region was marginally suitable for damask rose production (Table 5). The most important limiting factors for the damask rose plantation in the study area were climatic factors including mean temperature during the growing cycle, mean temperature during germination, and mean temperature during flowering. The high suitability class of S_1 was mainly distributed within the Western, middle, and Eastern parts of the province, while the mid part of the study area and some scattered parts within the East, Northeast, and Northwest exhibited moderate suitability for damask rose (Fig. 5). Also, the zonation map of land suitability exhibited that, along with elevating limitations in the South part of the study area, the suitability classes were reduced accordingly (Fig. 5). Marcelis–van Acker (1995) found that temperature is a critical factor in the growth of rose shoots, axillary buds, and following time. The low temperature affects the plant by increasing several photosynthetic enzyme activities like stromal fructose-1, rubisco, 6- bisphosphatase, sucrose-phosphate synthase, and also, anthocyanin content (Harborne, 1967; Ushio *et al*., 2008). Yadollahi *et al*. (2012) and Emad *et al*. (2012) demonstrated that damask rose is a tolerant medicinal plant to drought stress, diseases, and aphids and also is resistant to unsuitable environmental conditions.

Table 5. Suitability index and class and corresponding areas.

Land suitability class	Land index	Area	
		km²	%
S_1	80-100	665.6	2.61
S_2	60-80	24410.4	95.7
S_3	40-60	409.7	1.61
Total		25485.8	100

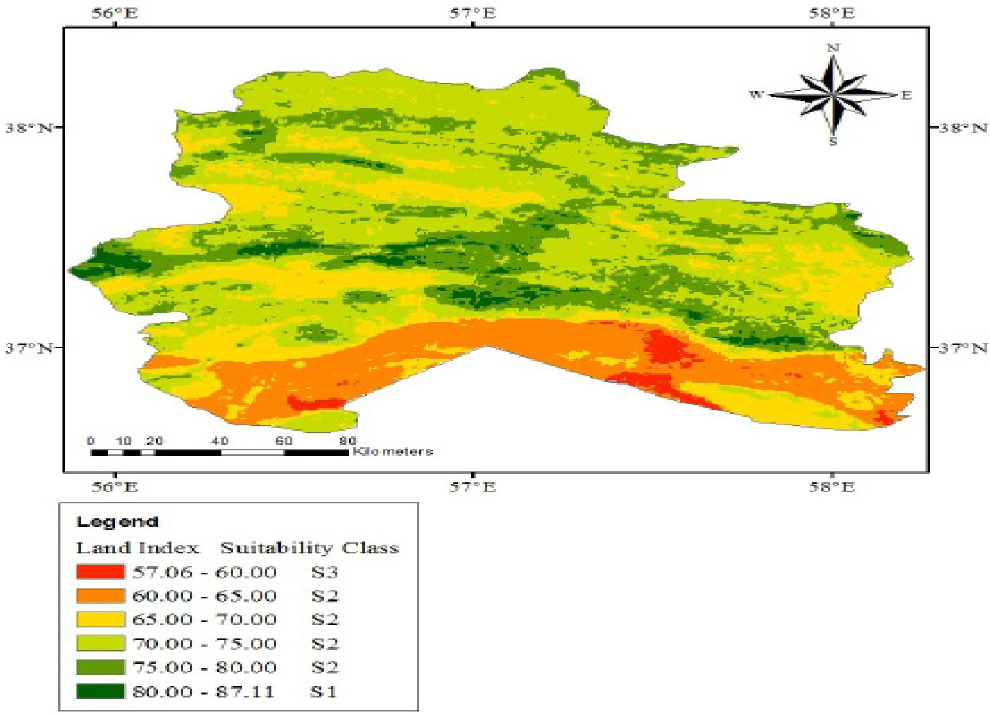

Fig. 5. The zonation of land suitability index for damask rose.

Model validation

Depending on the surface area of each land suitability class different numbers of samples were chosen, so that in the high, moderate, and marginally suitable classes some four, ten, and six fields were sampled, respectively. Comparing the land index values with the observed flower yields in each land suitability class in the study area revealed a high correlation (R^2=0.8505) between the land indices and flower yield, validating the zonation of the suitability classes in the region (Fig. 6). The results of our study showed that applying the multivariate factor analysis approach in land suitability evaluation for damask rose corresponds well with the yields samples gathered from selected fields.

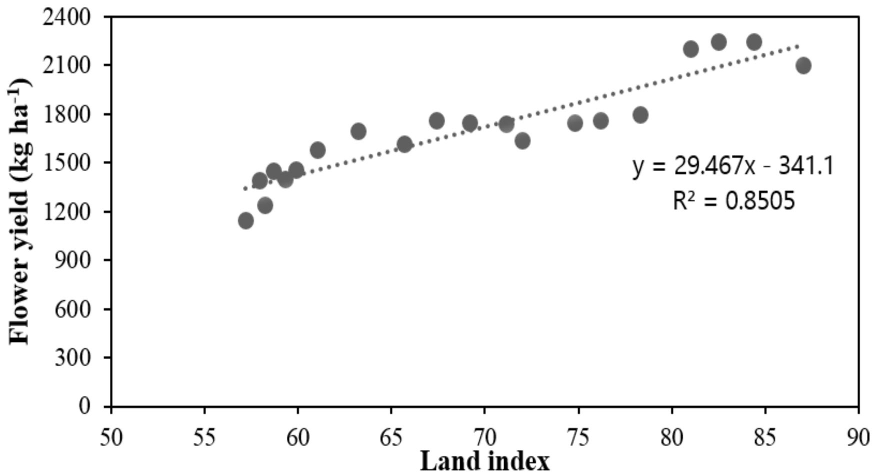

Fig. 6. Linear regression between the observed flower yield of damask rose and the land suitability indices in the study area.

CONCLUSION

Selection of medicinal plant species adapted to the arid and semi-arid areas and better usage of natural resources with high efficiency in these areas is extremely necessary for sustainable agriculture. One of the primary steps in the cultivation of any plant is consideration of the regions and requirements of the plant that is going to be planted there. Applying the multivariate statistical approach through factor analysis by principal component analysis (PCA) reduced the variables to a few factors and classified the research cases into specific clusters. Within the present study, the extracted 16 variables were processed, leading to four factors that explain about 90% of the total variance and eigenvalues greater than 1. The geographical distribution revealed that the points with very high suitability are laid within the Western parts of the study area, while the mid part of the study area and some scattered parts within the East and Northeast exhibited moderate suitability for damask rose. The points in high and moderate suitability zones are mostly affected mainly by climatic components. Also, the most important limiting factors for the damask rose cultivation within the study area were climatic components.

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