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Agroclimatic zoning of sugar beet in Kermanshah province using GIS

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Abstract

Population growth and ever-increasing need of human for food stuff necessitate agricultural development. Among agricultural products, sugar beet is cultivated as a strategic product by Iranian farmers and Kermanshah province ranks third in terms of cultivation as well as performance in Iran. Therefore, developing cultivation of this product requires more attention in this province. In general, one of the objectives of this study was to identify potential areas for the cultivation of sugar beet. Also, the following question was answered: Is agroclimatic zoning a proper method for determining potential areas for cultivation of sugar beet using Geographical Information System (GIS)? To this end, by analyzing the data and investigating effective climatic and environmental factors in sugar beet cultivation and locating potential cultivation areas, 9 factors of altitude, rainfall, temperature, slope, slope direction and land type, effective rainfall, water demand and evaporation and transpiration were investigated. In the next step, digital elevation model and maps of slope layers, elevation layers and land use were drawn. Then, qualitative and quantitative criteria and factors were identified by AHP technique and obtained layers along with their corresponding values were imported to Expert Choice software. The values were then compared with each other in pairs and weights of the criteria and sub-criteria were obtained. Finally, in GIS environment, the layers were prepared in AHP of raster layers according to the obtained values. Regarding point-wise factors such as temperature, rainfall, evaporation and perspiration, effective rainfall and water demand, Inverse Distance Weighted (IDW) interpolation method was used for obtaining maximum and minimum cores after getting the output from AHP software. Results of this study demonstrated that the province could be divided to four areas of potential, medium potential, low potential and non-potential. Potential areas for cultivating sugar beet were scattered in the province.

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Introduction

Weather and climate are among the most important data in agriculture. In fact, high quality and productivity of a product are related to climatic studies and no agricultural area can be economical without proper understanding of climate (Siami, 2004). A method for increasing production per unit area or optimum land utilization is to identify production capacity of each land and select appropriate use of its production capacity. In order to reach this goal, a suitable solution is to determine production potential and evaluate land suitability (Farajnia, 2008). Furthermore, establishing relative stability in delivering agricultural products to the market necessitates understanding ecological environment of plants, climatic condition and agroclimatology of different areas. Awareness of correlation rate between climate of an area and bioclimatic requirements of different products results in increased production efficiency, decreased loss and controlled supply and demand market (Sheikh Ahmadi, 2006). Also, providing sufficient food at reasonable price for people of the society is among the main elements of sustainable development in each country. Today, considering limitations in resources and ever-increasing population growth and therefore increase in demand for food products, the limited resources should be optimally used (Kamali *et al*., 2009). The planet we are inhabiting has limited resources and capabilities and can only respond to needs of the population corresponding to those capabilities. Therefore, humans are entitled to make all their efforts to utilize the nature and properly exploit it while making minimum damage, which could be controlled and compensated for as far as possible (Mousavinejad, 2002). Hence, knowing climate and investigating climatologic requirements of crops are among the most important factors in production and potential climatic facilities can be determined and maximally exploited in different areas by conducting meteorological studies of agriculture (Sari Sarraf *et al*., 2010). Therefore, the present study aimed to identify climatic potentials of Kermanshah province as well as potential areas for cultivating sugar beet in order to assist agricultural planners to optimally use climatic capacities and avoid its limitations. Variety in environmental conditions, including differences in climate, geology and topography, soil, water resources and vegetation, and their difference from one area to another result in different ecologic potential in different areas .Sugar beet (with scientific name of Beta Vulgaris) is a glandular plant with conical root from spinach family, beta genus and vulgaris species and its root should be completely placed into the soil in favorable conditions. It has male and female flowers which are formed either individually or collectively on leaflets (Evans, 1991). Using land without considering ecological differences of environmental potentials leads to adverse outcomes including erosion, desertification, earth pollution and environmental damage, which consequently endanger natural resources and prevent the environment from sustainable development. These cases are the result of using a land for cultivation which is not suitable for producing agricultural products. In these conditions, incorrect management and improper methods of land exploitation prepare the ground for reduction of resources and unreasonable land use by human (Farajzadeh *et al*., 2005).

Each agricultural product requires a special climatic condition and can grow only within a specific area. If products compatible with the governing climate of the area are selected as cultivation model, not only maximum land exploitation and efficiency are provided for farmers, but also minimum damage is made to that area's agricultural resources in a long run (Mirzabayati, 2005). Among agricultural products, sugar beet is cultivated as a strategic product by Iranian farmers and Kermanshah province ranks third in terms of cultivation as well as performance in Iran (Bureau for Statistics and Information Technology, Ministry of Jihad-e Agriculture, 2010).

In this study, according to agricultural capability of each area, the province was divided to different areas in terms of cultivation capability. Numerous works have been done on agroclimatic zoning; among the most important research on sugar beet cultivation is "Sugar Beet Handbook" which was published by Jakard and some other researchers in Brufer Baron Research Station, England. They concluded that the best efforts should be made for chlorophyll of the plant to absorb maximum radiation. Booth and Peter (1996) investigated the possibility of using climatic data for farming and succeeded in presenting a database for the considered data. Perera and Thillana (1991) studied land use in Sri Lanka using GIS and determined land suitability for cultivating agricultural products. They divided the considered land to 4 areas based on factors of slope, soil slippery and land capability and irrigation method and then investigated land suitability for each unit by analyzing maps and data related to GIS environment. Mavi and Mahi (1998) identified 7 agroclimatic zones in India using weekly soil moisture index during summer. Regarding importance of water and agricultural climatology, Wolfgang (2002) presented guidelines for making strategic agroclimatic decisions in major agricultural planning by providing information about time and place of available natural resources. In another study, Hejazy *et al.* (2003) concluded that remote sensing and GIS were effective tools in determining land use of different areas.

Shanwad (2003) believed in the importance of creating a database for agricultural resources and decision-making support systems at various agricultural levels and considered it as a serious duty of Indian geologists and agriculturists. Also in Iran, Teklu Biqash (2000) used GIS to zone wheat dry farming in Hamedan and divided lands of the area to three groups of weak, average and fine. By determining hydroclimatic calendar for sugar beet cultivation and harvesting in Khoy county, Ebrahimzadeh (2000) concluded that the first decade of April was the best period for cultivation and harvest period could start from October 12th (second decade of October) and end during third decade of October. In order to determine cultivation calendar of sugar beet and provide a model in Lorestan province, Dargahian (2001) used remote sensing and GIS for developing multiagent land use optimization model. Ghaemian *et al.* (2003) used a parametric method to evaluate land suitability for wheat, sugar beet and alfalfa cultivation in Piranshahr region and concluded that the most important limiting characteristics of these lands were their topography and flooding. Habibi *et al.* (2005) investigated effects of cultivation date and bush density on root performance and sugar beet fineness. Their results showed that short growing season, due to delay in cultivation, resulted in plant inability for timely expansion of its canopy and better use of environmental potential; therefore, autumn coldness reduced growth velocity of sugar beet before reaching its maximum vegetative growth and led to generating smaller roots. Generally, delay in cultivation resulted in reduced root performance and white sugar on the one hand and increased fructose percentage on the other. Alijani *et al.* (2007) identified suitable lands for cultivating barberry in South Khorasan province using AHP method in GIS environment. In a study entitled "Evaluating land suitability and determining sugar beet production potential in Yekanat Plain, Marand, Iran, Farajnia (2008) measured soil properties, evaluated land suitability and determined sugar beet production potential there. Results of this study demonstrated that Marand region was an unsuitable place for dry farming of sugar beet because growth period of this product was outside of growth period of the region (November 12 to May 05). However, there was no climatic limitation for wet farming of sugar beet. Amani (2010) studied compatibility rate of sugar beet cultivation with climatic conditions in Torbat-e Heidarieh County using GIS. Also, Hashemi (2012) performed agroclimatic zoning for strawberry cultivation using GIS in Kurdestan province. The objective of this study was to use GIS for identifying potential areas for cultivating sugar beet cultivation throughout Kermanshah province. Results of this study can be used as a proper basis for agricultural projects in this province.

Materials and methods

Kermanshah province is located in the middle of western part of Iran with an area of 25008 km^2 within 45^o 24' and maximum 48^o 07' of east longitude and 33^o 40' and maximum 35^o 18' of north latitude. This province meets Kurdestan province from north, Lorestan and Ilam provinces from south and Hamadan province from east and has 330 km of common border with Iraq. In order to carry out the study, statistics from 5 synoptic stations of the province and data from Department of Agriculture were used (Table 1). After identifying effective parameters, spatial database was created using GIS technique and finally multiparametric analyses and simultaneous GIS analysis were used to extract potential areas for cultivation. Figure 1 shows location of rain gauge stations within the studied area.

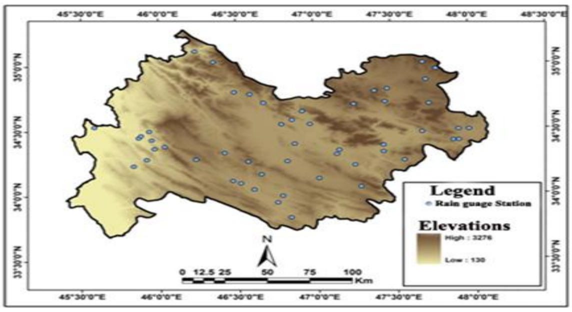

Fig. 1. Location of rain gauge stations in the studied area.

Table 1. Characteristics of synoptic stations in the studied area.

Station	Kermanshah	Sarpole-e Zahab	Eslamabad-e Gharb	Ravansar	Kangavar
Altitude from sea level (M)	1318.6	545	1384.8	1379.7	1460
Longitude	47° 09'	52° 45'	46° 28'	46° 39'	47° 9'
Latitude	21° 34'	27° 34'	34° 07'	34° 43'	34° 50'
Average of minmum temperatue (C°)	6.6	12	5	8	6
Average of maximum temperature (C°)	4.23	27.9	22.1	21.4	21.6
Relative humidity in percent	45	47	51	45	53.4
Average annual rainfall (mm)	6.429	443.5	491	520.4	478.1
Average wind speed (knot)	6.4	3.3	3.1	5.5	3.9
Annual sundial	2962	3068	3074	3024	3162.1

This study was based on field, tool and library methods. First, using topographic maps, range of the studied area was determined. Topographic maps, geological maps, aerial maps of the area and 2002 IRS satellite images, rainfall data and temperature of meteorology organization were used as main study instruments. Considering the purpose of this paper, to investigate potential areas for cultivating sugar beet in Kermanshah province, 9 factors of altitude, rainfall, temperature, slope, slope direction and land type, effective rainfall, water demand, evaporation and perspiration were investigated as independent variables. In this regard, topographic and geological maps were imported to Arc GIS software as basic data. Then, digital elevation model and maps of slope layers, elevation levels and land uses were drawn. Afterward, qualitative and quantitative criteria and factors were identified and then they were determined using tools such as interview and questionnaire in general and by Delphi method in particular. Then, factors of altitude, topographic slope, slope direction, land type, rainfall, temperature, water demand, evapotranspiration and effective rainfall were weighted by AHP technique by using Expert Choice software in 3, 4, 4, 4, 3, 4, 4, 4 and 4 classes, respectively; their values were compared in pairs and weight of the criteria and sub-criteria was obtained. To determine superiority of the criteria, some questionnaires were first prepared and completed using Delphi method. Then, order of the criteria was imported in AHP and compared in pairs. Final results were transferred to GIS software, where a column called code was defined in AHP for surface layers considering the obtained results. Afterward, the desired raster layers were prepared with respect to the codes. Weight value of factors depended on value range of factors, which was the difference between minimum and maximum values attributed to each factor (Amani, 2010). For point-wise factors such as temperature, rainfall, evapotranspiration, effective rainfall and water demand, IDW interpolation method was used after receiving the output from AHP in order to obtain maximum and minimum cores. Finally, by overlapping the information layers, the final map was prepared.

In order to determine climatic parameters required for sugar beet cultivation including temperature, evaporation and perspiration, effective rainfall, water demand and effective rainfall, statistics of meteorology station in the province was used. To prepare land use and soil type maps, land suitability maps of the studied area which were obtained from National Soil and Water Institute and 1:100000 geology maps were utilized. Furthermore, information about the cultivated area and annual production rate was obtained from statistics and information of agricultural products published by Ministry of Jihad-e Agriculture.

As mentioned earlier, 9 variables affecting sugar beet cultivation of the area including water demand, effective rainfall, evaporation and perspiration, altitude, slope, slope direction, rainfall, temperature and land type were investigated and their corresponding weights were prepared in Export Choice software. Latitude, evaporation and perspiration, water demand, light, wind, altitude and day length were environmental and climatic factors which had a considerable role in sugar beet performance. Maximum growth rate of sugar beet occurred at average daylong temperature of 20 to 32° C. However, in case of sufficient soil moisture, the plant could easily tolerate temperature up to 35-40° C. Sugar beet is cultivated in 30 to 60⁰ north latitude, from Cairo in Egypt to Helsinki in Finland and generally throughout Europe, Asia, North Africa and North America along with altitude of 0 to more than 2000 m above sea level (depending on the latitude). The amount of evaporation and perspiration in a sugar beet farm can vary from 500 to 1500 mm/ha depending on climatic conditions and production factors. Successful dry farming of sugar beet requires minimum 500 mm water (sum of moisture reserve and rainfall during growth season with proper distribution) (Khajepour, 2008). Relative water consumption of sugar beet is not very higher than other crops; however, its absolute water consumption is high per hectare, especially at high production rate of dry material. Sugar beet has special need for water during its growth season. Rainfall distribution is more important than rainfall rate (Peter, 2001). Maximum water demand of sugar beet is from canopy formation on and up to 4 to 6 weeks before harvesting (Heidari Zoleh, 2008). Visible light is a part of sunlight spectrum which is the source of energy for photosynthesis in plants (Franklin *et al.*, 1999). The main goal of farming is to maximize absorption of sun radiation; since leaves of sugar beet is almost horizontal, 85 to 95% of indirect light received by leaf level index is equal to 3 or 4; this figure is much less than that of grains. A simpler and sometimes easier way is to evaluate canopy coverage. Canopy coverage is directly and indirectly related to sunlight absorption (Cooke *et al.*, 1997. It is difficult to evaluate effect of wind on crops; however, comparing the plants exposed to wind and those not exposed to wind indicates effect of wind on reduction of plant performance. Using a shelter for wind prevention increases grain production by 10 to 30%. For instance, rate of product increase in sugar beet is from 1 to 33% (Nouri, 2005). Increased altitude and decreased average annual temperature and summer temperature cause prevention of many variations and reduce probability risk of harvesting failure. Day length, photoperiod and corresponding plant growth reaction are called photoperiodism. Due to the presence of photoperiodism in crops, day length is considered an important environmental factor. In addition, day length also determines duration of light absorption by plants.

Analytic Hierarchy Process (AHP)

Analytic hierarchy process is one of decision-making systems for multiple factors, which was designed by Thomas L. Saati (1980) based on stable expert knowledge and was then further developed by Saati and

Vager (2001) (Aami Azghadi *et al.*, 2011). Analytic hierarchy process is a flexible, powerful and simple method for decision making when contrary decision-making criteria make the decision-making process difficult and decision must be made in a multi-dimensional space. In this condition, multi-criteria evaluation methods are used since, in these methods, every criterion is considered to have a separate axis or "dimension". A major method for performing a test in AHP is pair-wise comparison method (Hadiani *et al.*, 2011). The main advantage of AHP is that it helps researchers to divide a complex problem to some parts using a hierarchical structure; then, they are logically attributed weights and different factors are prioritized according to their importance. Weight of different items is only obtained by comparing two elements in each stage (Azimpour *et al.*, 2010). Another advantage is calculation of compatibility rate; once obtained, this rate enables revision of judgments (Azimi Hosseini, 2011).

Results and discussion

In this study, analytic hierarchy process was used based on pair or binary comparisons, which make judgment easier and increase accuracy of calculation. Delphi model was also utilized for locating; thus, weighing form was distributed among the experts and final criteria were determined after reviewing climatic and environmental characteristics of the area. As was observed, criteria and sub-criteria were imported to Expert Choice software and 9 effective criteria and their corresponding sub-criteria of sugar beet production were compared with each other in pairs and the obtained results were separately shown for each of them. Final results were transferred to GIS, where a column called code was defined for polygony layers considering their obtained values in AHP. Then, the required raster layers were prepared based on these codes. For point-wise factors such as temperature, rainfall, evaporation and perspiration, effective rainfall and water demand, IDW interpolation method was used to calculated maximum and minimum cores after obtaining AHP output. Finally, the final map was prepared by overlapping the related information layers, which demonstrated suitable zones for cultivating sugar beet. Regarding environmental conditions and requirements of sugar beet, weight allocation and classification, area and coverage percentage of each class were done in information layers. Table 2 shows all the effective environmental and climatic parameters in sugar beet cultivation based on Boolean weighing model and AHP software. Finally, the final map was prepared by overlapping related information layers, which demonstrated suitable zones for cultivating sugar beet (Figs. 2 and 3).

Table 2. Characteristics of weighing layers and classification based on Boolean model and AHP

Considered layers	Weight of layers using AHP model	Classification of layers	Domain of classes	Perecnetage of area coverage	Area (km^2)	Weight based on Boolean model	AHP value (Delphi)
Water demand	385	Excellent	<784	63.16	15739.36	1	9
	306	good	784-1019	10.16	2533.92	1	7
	265	average	1019-1236	13.08	3259.88	0	6
	44	Poor	>1236	13.57	3383.59	0	1
Effective rainfall	417	Excellent	>50	8.74	2560.67	1	8
	319	good	47-50	11.95	3797.47	1	6
	159	average	20-47	27.46	5396.86	0	3
	106	Poor	<20	51.85	13161	0	2
Evaporation and	401	Excellent	<883	20.37	5076.59	1	9
	323	good	883-1337	22.49	5605.80	1	7

perspiration	185	average	1337-1733	47.17	11753.47	0	4
	91	Poor	>1733	9.95	2480.47	0	2
Land type	422	Excellent	Alluvial Plain	54.60	13600.16	1	9
	339	good	Plateau	22.74	5664.19	1	7
	144	average	Fan debris	7.72	1924.94	0	3
	95	Poor	Mountains	14.93	3719.01	0	2
Rainfall	389	Excellent	>1000 mm	28.2	7017.38	1	9
	348	Suitable	950-1000	53.04	13200.75	1	8
	263	Poor	<950	18.75	4666.08	0	6
Temperature	469	Excellent	<10°C	10.78	2683.46	1	8
	292	good	10-12	31.17	7756.51	1	5
	180	average	12-14	39.83	9913	0	3
	59	Poor	>14	18.2	4531.10	0	1
Topography	439	good	<1300 m	75.45	18776.33	1	9
	357	average	1300 -2300	22.71	5651.57	1	7
	205	Unsuitable	>2300	1.83	456.33	0	4
Slope	371	Excellent	<4 degree	33.51	8331.19	1	9
	359	good	4-8	26.82	6669.24	1	7
	206	average	8-12	17.72	4405.61	0	4
	64	Poor	>12	21.93	5452.11	0	1
Slope direction	419	Excellent	202.5-247.5	11.90	4305.42	1	8
	318	average	247.5-292.5	16.20	3233.26	1	6
	211	Poor	212.5-157.5	9.87	2172.57	0	4
	53	Very poor	292.5-337.5	8.5	2423.61	0	1

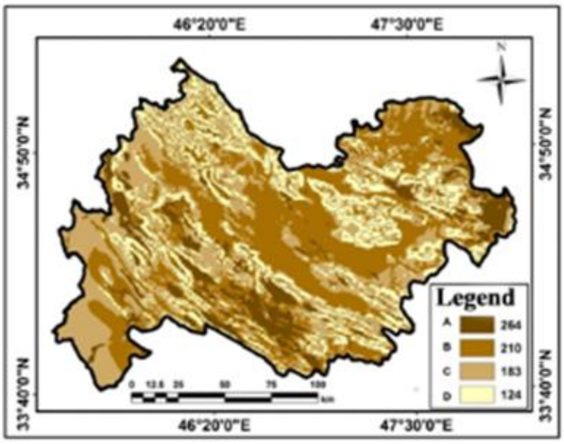

Fig. 2. **F**avorable areas for sugar beet cultivation using AHP model.

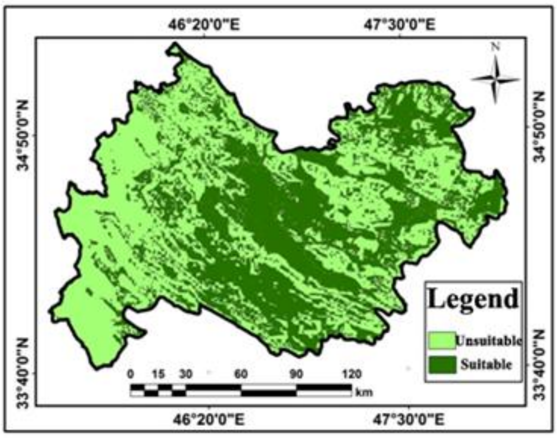

Fig. 3. Final map of Boolean model for the studied area.

After performing various steps, potential areas for sugar beet cultivation can be divided to 4 areas of potential, medium development, low development and defective areas (Table 3).

Table 3. Potential areas for cultivating sugar beet.

Name of the area	Area (km^2)	Percentage of area coverage	Potentiality rate of the area in terms of cultivation
A	2860.3	10	Fully potential
B	6220.2	25.2	Medium potential
C	4695.3	16.4	Low potenital
D	11140.5	48.4	Non-potential

Fully potential areas for sugar beet production were 2860.3 km^2, i.e. 10 percent of the total studied area. The area with average sugar beet development covered 6220.2 km^2 (25.2%) of the province area. The zones with low and defective development with 4695.3 (16.4%) and 11140.5 (48.8%) km^2 ranked third and fourth. As can be observed, maximum area of this land was not suitable for sugar beet cultivation; thus, growth of the product must be developed by adopting proper methods and preparing favorable conditions.

Conclusions

In order to investigate suitable places for cultivating sugar beet in Kermanshah province, 9 effective variables in sugar beet cultivation in this area which included water demand, effective rainfall, evaporation and perspiration, altitude, slope, slope direction, rainfall, temperature and land type were investigated by Delphi technique, Boolean model and finally AHP model. Then, their corresponding weights were prepared in Expert Choice software. Results of this study regarding altitude factor demonstrated that altitude levels of 1300-2300 m, which accounted for 75.45% of the land (18776.33 km^2), were suitable for sugar beet cultivation. Slopes of less than 4 degrees, which contained 33.51% of the province area (8331.19 km^2), were suitable for cultivation. The results showed that slopes with western slope, which were located at 202.5 – 247.5, were the best and most suitable slopes for sugar beet cultivation. Regarding the rainfall, it must be mentioned that 600-950 mm of rainfall, which covered 7017.38 km^2 or 28.2% of the area, was considerably effective in sugar beet cultivation. Also, temperatures of less than 10 °C were the most optimum temperature for sugar beet cultivation. Suitable lands in terms of temperature distribution were scattered in northwest and central areas of the province and unfavorable lands in terms of temperature for sugar beet cultivation were in westerns areas of the province. Coefficients resulting from pair comparison demonstrated superiority of temperatures of less than 10 °C for sugar beet cultivation. From capability viewpoint, water demand of less than 784 was evaluated as excellent, which covered 3383.59 km^2 (13.57%) of the province, and pair comparisons performed in Expert Choice software also confirmed this finding. Evaporation and perspiration of less than 883 covered 5076.59 km^2 (2037%) of the total area. Effective rainfall in this area was evaluated to be more than 50 mm. Land types were divided to 4 groups according to their capability for cultivating sugar beet; Alluvial Plain with 54.60% (13600.16 km^2) were the best places for cultivating sugar beet and their distribution could be seen in northern and western parts of the province.

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