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Agroclimatic zonation to evaluate the feasibility of autumn sowing of sugar beet in Razavi Khorasan and South Khorasan provinces

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ABSTRACT

Autumn-sown sugar beet outperform spring-sown ones in terms of costs and water use efficiency. In Razavi Khorasan and South Khorasan provinces, sugar beet is sown only in spring. Therefore, it is imperative to study the feasibility of autumn sowing of sugar beet. In order to use geographic information system, climatic parameters including temperature and rainfall in these two provinces were collected. Then, the occurrence of cumulative thermal unit, crop biomass productivity index, vernalizing hours, freezing, rainfall, and day length probability were estimated for each station. The slope and elevation layers of the regions were derived from digital elevation model. Zonation map of the effective layers as well as the final map were drawn using analytic hierarchy process in ARC GIS medium. Results showed that sugar beet is likely to bolt in most parts of Razavi Khorasan and the central parts of South Khorasan provinces. In southwestern parts of South Khorasan province, the total vernalizing hours was less than that required by sugar beet. Although, less than 50 mm precipitation during the growing season in southern parts of South Khorasan province impairs their competitive advantage for autumn sowing of sugar beet, most regions with >190 mm rainfall are faced with freezing, lack of appropriate GDD interception , and vernalization. According to the final zonation map, 4.90% of the lands are very appropriate, 16.74% are appropriate, 47.98% are moderately appropriate, and 30.38% are inappropriate for autumn sowing of sugar beet.

Keywords: climatic zonation, sugar beet, geographic information system, autumn sowing

INTRODUCTION

Water is the most limiting factor for agriculture practices in Iran; therefore, specific consideration was applied to enhance the efficiency of its usage in crop production. Autumn planting of sugar beet has drawn attentions in order to maximize rainfall usage (Koulivand 1988). Indeed, autumn planting of sugar beet has more economic benefits than spring planting (Jaggard and Werker 1999). In a study in US, Kaffka (1996) found that sugar beet was a suitable crop for sustainable agriculture. Vernalization, bolting, and freezing damages are considered as main hurdles for the development of autumn planting of sugar beet (Reinsdorf and Koch 2013).

The identification of proper areas for autumn sugar beet planting in Iran is a priority of the Ministry of Jihad-e-Agriculture and the Sugar Beet Seed Institute. However, considering the vast area of the provinces in question and their diverse climate, a plethora of research projects are required to identify these areas which is clearly costly. This is the main reason of why no comprehensive study has been undertaken yet. One alternative strategy that can help policy-makers in a more cost-effective way and lay the ground for the development of this planting regime is *agro-ecological zoning*. Agro-ecological zoning enables the anticipation of the production risks on the basis of climatic parameter variation, plant growth,

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and development stage (Ati et al. 2002, Bishnoi 2010). Using geographical information system (GIS) and growth simulation models, researchers have zoned Europe for wheat planting in terms of water potential and limitations (Reidsma et al. 2009).

Agro-ecological zoning of Khorasan provinces in Iran to recognize its potential for spring sugar beet planting showed that 4% of the lands in this province were in perfectly appropriate zone, 18% were in appropriate zone, and 32% were in moderately appropriate zone. Finally, 46%, mainly located in the southern parts of Khorasan-e Razavi province and most parts of Southern Khorasan province, were found to be inappropriate for spring planting of sugar beet (Sanjani 2013). In a similar study in Iran on determining the suitability of the Torbat-e Heydarieh region for spring sugar beet planting, it was revealed that 59.61%of the lands were highly apt for this crop, but 24.49 lacked the suitability. Rokh and Kadkan plains in the north of the county were found to be the most suitable places followed by Markazi plain that was zoned to be suitable (Khosravi et al. 2014).

It has been reported that the initiation of bolting is controlled by two genes, one responsible for plant response to cold temperatures (vernalization phase) and the other responsible for plant response to day length (post-vernalization phase, Van Dijk 2009, Marquardt et al. 2006). Annual sugar beets can bolt with no requirement for vernalization and/or short day conditions. But, biennial sugar beets need both vernalization and long days to bolt (Abe et al. 1997). The time required for vernalization varies in the range of 8-14 weeks, depending on bolting resistance and genetic material of the cultivars (Cooke and Scott 1993). The threshold of vernalization hours in autumn-sown sugar beet is 140 hours, but resistant cultivars can tolerate as high as 165 hours (Milford et al. 2010). Reinsdorf and Koch (2013) reported that at temperature lower than -6°C, roots may damage. They conducted trials in four regions with different climatic conditions in Central Europe and found that 10-35% of freezing damage occurred in autumn-sown sugar beet fields.

The effect of latitude change is of crucial importance on flowering time of the crops (Franks et al. 2007, Reusch and Wood 2007). There are not many reports about the variations of day length requirement or the simultaneous need for day length and vernalization across various latitudes (Heide and Sonsteby 2007). The need for vernalization and photoperiod, as well as their interactions, has caused that plants with same *bb* genome require various vernalization durations and longer photoperiod (Van Dijk 2009). The bolting-resistance cultivar 'Saxon' should be exposed to day length of 18 hours for at least 8 and 21 days in order to respond to day length and initiate bolting, respectively. Sensitive cultivars respond to long day length immediately after vernalization, whereas resistant ones should be exposed to inductive day length for at least 8 days in order to bolt (Chegini 1999).

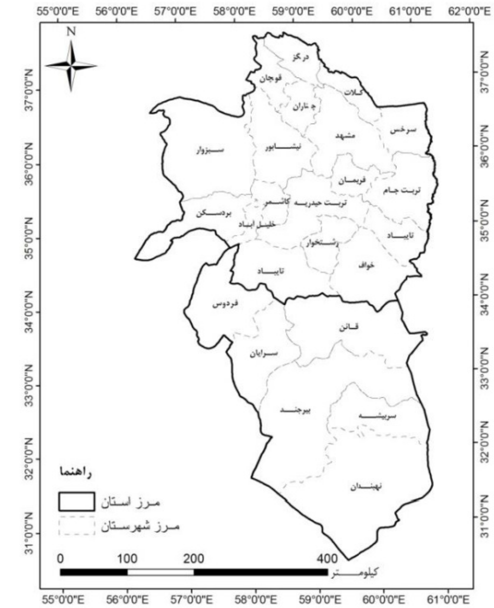

Figure 1. Map of Razavi Khorasan and South Khorasan provinces including their counties

Given the unique climatic conditions of Iran, it seems feasible to find new zones for autumn sugar beet planting.

MATERIALS AND METHODS

The present study was conducted across a vast area including two provinces of Khorasan-e Razavi and Southern Khorasan. These two provinces, together, occupy an area of 204,091 km^2. Figure 1 shows their borderlines and the name of the counties. The topographic maps have been prepared by the Iran National Cartographic Center at the 1:250,000 scale.

The criteria to select the meteorological stations for the study were the duration of statistical period and the availability of all data (the lack of missing data). Also, the statistics and data of some stations outside the research scope were used as auxiliary points and markers to find isothermal and isoline regions because of the availability of

Table 1. Geographic characteristics of the synoptic stations in Razavi Khorasan and South Khorasan provinces

Sr. No.	Station name	Longitude (X)	Latitude (Y)	Altitude (Z) (m)
1	Torbat-e Jam	60°35'	35°15'	950.4
2	Kashmar	58°28'	35°12'	1109.7
3	Nehbandan	60°02'	31°32'	1188
4	Birjand	59°17'	32°53'	1504
5	Mashhad	59°38'	36°16'	999.2
6	Quchan	58°30'	37°04'	1287
7	Sabzevar	57°43'	36°12'	977.6
8	Bojnord	57°19'	37°28'	1091
9	Sarakhs	61°10'	36°32'	235
10	Gonabad	58°41'	34°21'	1056
11	Zabol	61°21'	31°20'	489.2
12	Qaen	59°11'	33°44'	1439
13	Nishapur	58°48'	36°16'	1213
14	Boshruyeh	57°25'	33°51'	879
15	Ferdows	58°11'	34°01'	1292
16	Torbat-e Heydarieh	59°13'	35°16'	1450.8
17	Tabas	55°56'	33°36'	711
18	Khur Birjand	58°26'	32°56'	1117.4
19	Golmakan	59°17'	36°29'	1176
20	Sarbisheh	59°47'	32°36'	1846

their long-term statistics and their closeness to the studied site (Table 1). Data homogeneity was checked by Run Test.

Synoptic stations record temperature every three hours. So, we did not have access to hourly temperatures and we had to estimate them, in which the hourly temperatures were estimated by a two-sine model using maximum and minimum daily temperatures (Helali 2008).

Day length and sunrise hour were determined by the program supplied by National Oceanic and Atmospheric Administration of the US (Cornwall et al. 2001). Sowing and harvest dates around the meteorological stations were derived from results of research projects as well as the temperature thresholds of the crops at sowing and harvest stages.

Calculations were done in Matlab R2013b Software. Then, the Easy Fit 5 Software was used to calculate the probability of the occurrence of each factor. To determine the best method of interpolation, we assessed the regression models, inverse distance weighting, kriging, and co-kriging. Gradient equations were derived by the Minitab 17 Software, and data were analyzed and the zonation was performed by the ARC GIS10.2 Software. Finally, after weights of effective layers were calculated, analytic hierarchy process (AHP) was employed to extract the final map. Studied regions were divided up into four classes in terms of their suitability for sowing as very suitable, suitable, moderately suitable, and unsuitable.

Sugar beet growth stages including germination (from sowing to emergence), initial growth (from two-leaf to the end of six-leaf stage), and main growth (from six-leaf stage to harvest), were also estimated for each station. The initiation and termination of each growth stage were determined by growing degree-days (GDD) whose initiation point was set to the sowing date in each individual station and then, the plants thermal unit requirements to transit from one certain developmental stage to the next were estimated by Equation (1). The reference temperature for sugar beet was set to 5°C in this equation (Hundal et al. 1977).

$$GDD = \sum_a^b \left(\frac{T_{\max} + T_{\min}}{2} \right) - T_b \quad (1)$$

where

T_{max} = maximum daily temperature in °C,

T_{min} = minimum daily temperature in °C,

T_b = reference temperature in °C (5°C for sugar beet),

a = developmental stage onset date, and

b = development stage end date.

We, also, estimated crop biomass productivity index. The index represents the total temperatures appropriate for growth during the growing season and for dry matter accumulation. It acts as the difference between daily temperature and the optimal temperature for growth and is calculated by Equation (2, de Pauw, 2002).

$$CBPI = \sum_{i=GP_{on}}^{GP_{end}} (ATI) i.j \quad (2)$$

where *CBPI* denotes crop biomass productivity index, *j* represents crop group, *i* shows trend number, *ATI* is adjusted thermal increment, and

Table 2. Equations used to interpolate the parameters by gradient methods

Parameter	Equation	R^2
The probability of the occurrence of <-15°C during the growth period	P1 = -3.15 + 0.0317 X + 0.0342 Y + 0.000194 Z	0.66
Day length (14 days before harvest)	P2 = 2.74 + 0.0545 X + 0.2016 Y + 0.000737 Z	0.85
GDD from sowing until harvest	P3 = 7740 – 30.7 X – 96.2 Y – 0.345 Z	0.72
Crop biomass productivity index from sowing until harvest	P4 = 4043 – 15.6 X – 32.38 Y – 0.1171 Z	0.65
Total vernalization hours	P5 = -770 + 5.62 X + 16.95 Y + 0.0522 Z	0.91

X = latitude; Y = longitude; Z = altitude

GP_{on} and GP_{end} represent growing period onset and end dates, respectively.

ATI is obtained on the basis of mean daily temperature using Equation (3).

$$\begin{aligned}
&ATI = 0 && \text{if } T_{day} \le T_0 \text{ or } T_{day} \ge T_X \\
&ATI = T_{day} - T_0 && \text{if } T_{day} \ge T_0 \text{ and } T_{day} < T_{opt1} \\
&ATI = \frac{T_{opt1} + T_{opt2}}{2} && \text{if } T_{day} \ge T_{opt1} \text{ and } T_{day} \le T_{opt2} \\
&ATI = T_X - T_{day} && \text{if } T_{day} > T_{opt2} \text{ and } T_{day} < T_X
\end{aligned} \tag{3}$$

where
T_{day} = daily temperature,
T_0 = reference growth temperature,
T_{opt1} = lower limit of the threshold temperature above which dry matter accumulation rate is maximized,
T_{opt2} = upper limit of the threshold temperature above which dry matter accumulation rate is reduced, and
T_X = temperature above which no dry matter is accumulated.

T_0, T_{opt1}, T_{opt2}, and T_X are 5, 15, 20, and 23°C for sugar beet, respectively (de Pauw et al. 2000).

The previous models do not consider the fact that temperatures in the range of 0-12°C have varying quantitative effects on vernalization (Stout 1946, Bosemark 1993, Bell 1946). For the first time in Iran, we estimated vernalization by the following model in which various weights are assigned to temperatures that influence vernalization (0-1, 1-2, 2-3, …, 13-14°C, Milford et al. 2010). Equation 4 represents chilling weight on the basis of specific hourly temperature (Jaggard et al. 1983).

$$Y = -1.256 + (1.260 + 0.131x) \times 0.9357^x \tag{4}$$

where
y = chilling temperature, and
x = specific hourly temperature.

This method requires daily hourly temperatures that have been calculated by Khalili (2005)'s model.

Before rainfall data were localized, we ensured their normality. Then, rainfall data were interpolated by kriging method. For final zonation, it was imperative to assign weights to each individual layer and to specify their relative importance. So, a questionnaire was designed and administered to experts. Then, their opinions were fed into a pairwise comparison matrix in Expert Choice software. Weights of each parameter (main factors) and sub-factors (categories of each main parameter) were calculated and final weight was calculated as the multiplication of these two values (Table 3). After parameters were compared on a pairwise basis in Expert Choice, the inconsistency rate was found to be 0.06 for the comparisons. Since this was smaller than 0.1, the comparisons were acceptable (Saaty 1980).

We employed analytic hierarchy process (AHP) and after weights of effective layers were obtained, the final map was derived from the sequential multiplication of the matrices. The map was divided up into four categories of very suitable, suitable, moderately suitable, and unsuitable in terms of the potential for planting.

Results and Discussion

Most meteorological parameters are influenced by elevation, so that the best way to interpolate data is to use elevation as well as latitude and longitude (Taiti et al. 2006).

Table 2 shows the calculation of gradient equations which were used to interpolate the parameters. Also, the domain and talent of the studied layers are separately presented in Table 3.

Elevation from sea level

Using digital elevation model, elevation map was drawn for the studied provinces (Figure 2). Regions where the elevation was less than 1000 m from sea level were completely suitable for autumn-sown sugar beet. These lands are mostly located in the south of South Khorasan province. As elevation increased, the risk of chilling risk was

Table 3. The weights assigned to main factors, the strata of the indices, and the susceptibility of the studied layers

Indices (main factors)	Weight of main factor	Classification of layers	Strata of each factor	Percent of strata of each factor	Final weight	Area (%)	Area (m^2)
Altitude (m)	0.21	Very appropriate	240-1000	0.495	0.10395	12	24438.23
		Appropriate	1000-1400	0.310	0.0651	21	45001.81
		Moderately appropriate	1400-1800	0.134	0.2814	36	75893.68
		Inappropriate	1800-3249	0.061	0.1281	31	65594.64
Slope (%)	0.21	Very appropriate	0-4	0.573	0.12033	3	6712.02
		Appropriate	4-8	0.271	0.05691	5	10601.89
		Moderately appropriate	8-12	0.110	0.0231	16	32716.43
		Inappropriate	>12	0.045	0.00945	75	154036.4
Precipitation (mm)	0.199	Very appropriate	>190	0.546	0.108654	48	101680
		Appropriate	120-190	0.232	0.046168	34	71048
		Moderately appropriate	50-120	0.138	0.027462	14	29664
		Inappropriate	<50	0.084	0.1764	4	8584
Vernalization (GDD)	0.114	Very appropriate	<140	0.510	0.05814	60	125713.9
		Appropriate	140-170	0.271	0.030894	27	57938.63
		Moderately appropriate	170-200	0.152	0.017328	10	20141.26
		Inappropriate	>200	0.067	0.007638	3	7164.779
Minimum temperature (°C)	0.071	Very appropriate	>-7	0.587	0.041677	5	10264.55
		Appropriate	-11 to -7	0.225	0.015975	31	64779.31
		Moderately appropriate	-15 to -11	0.131	0.009301	41	86466.94
		Inappropriate	<-15	0.057	0.04047	23	49397.64
Growth degree-days (degree day)	0.071	Very appropriate	2600-2732	0.604	0.042884	12	24438.23
		Appropriate	2300-2600	0.201	0.014271	21	45001.81
		Moderately appropriate	2000-2300	0.121	0.008591	36	758793.68
		Inappropriate	1307-2000	0.074	0.005254	31	65594.64
Crop biomass productivity index	0.043	Very appropriate	2000-20445	0.546	0.023478	3	6712.02
		Appropriate	1900-2000	0.232	0.009976	5	10601.89
		Moderately appropriate	1800-1900	0.138	0.005934	16	32716.43
		Inappropriate	1562-1800	0.084	0.003612	75	154036.4
Day length (hr)	0.082	Very appropriate	12.7-13	0.486	0.039852	48	101680
		Appropriate	13-14	0.285	0.02337	34	71048
		Moderately appropriate	14-15	0.173	0.014186	14	29664
		Inappropriate	15-15.7	0.056	0.004592	4	8584

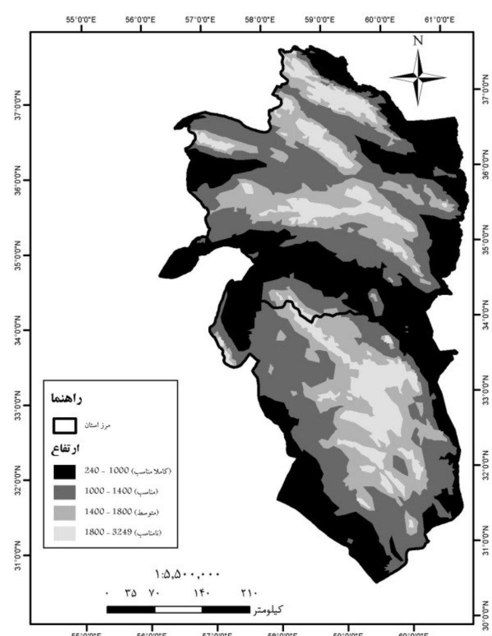

Figure 2. Elevation map of Razavi Khorasan and South Khorasan provinces generated from digital elevation model

intensified, especially at >1800 m elevation. The central parts of the two studied provinces had high elevation and were not appropriate for autumn sowing.

Slope

Sugar beet is sensitive to humidity variation at germination stage. Water runoff is higher on steeper slopes making mechanization very difficult. As well, sloped lands are posed to severe erosion. Lands with <8% slope are suitable for most crops (Makhdoom 1995).

Figure 3 displays the slope map of the studied provinces. Lands with <4% slope are classified as completely suitable regions for sugar beet growing. Perfectly sloped lands are mostly located in the south of Razavi Khorasan and the east of South Khorasan. Lands with 4-8% slope are suitable for sugar beet growing. Lands with >12% slope are considered as unsuitable and zoned within unsuitable regions.

Growing degree-days

Unlike plants with determinate growth, sugar beet has no specific technological maturity time. The crop is harvested earlier in regions with limited late-season temperature. In lands where the crop receives adequate GDDs are classified as susceptible lands for autumn planting of sugar beet.

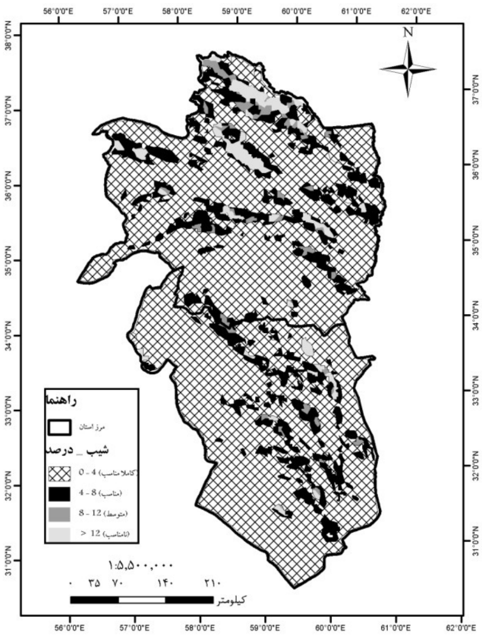

Figure 3. Map of slope percentage derived from digital elevation model of Razavi Khorasan and South Khorasan provinces

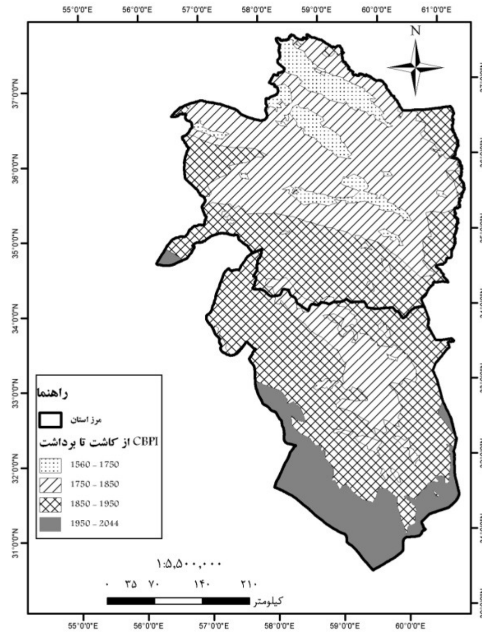

Figure 5. The zonation map depicting >75% probability of the occurrence of crop biomass productivity index from sowing to harvest in Razavi Khorasan and South Khorasan provinces

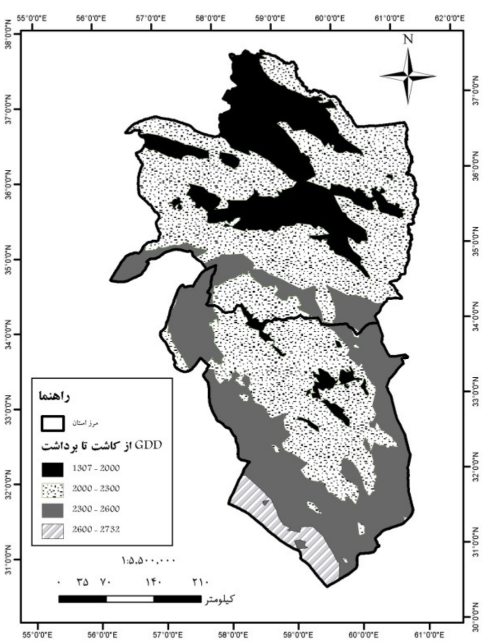

Figure 4. The zonation map depicting >75% probability of the occurrence of cumulative thermal units in terms of growth degree-days (hours) from sowing to harvest in Razavi Khorasan and South Khorasan provinces

Autumn-sown sugar beet requires 2500-2900 GDDs from sowing to harvest (Hossein poor 2007, Javaheri et al. 2006). In this study, we first calculated GDDs from sowing to harvest for each individual station. Then, the digital zonation map of >75% probability of the occurrence of accumulated thermal units in terms of (hourly) GDD was prepared for the studied regions (Figure 4). As is evident in Figure 4, all regions receive insufficient GDDs except for the southern parts of Birjand and Nehbandan counties. Regions that receive <2000 GDDs are unsuitable for autumn sowing of sugar beet so that autumn-sown sugar beet will produce a very low final yield in these regions. Regions receiving 2000-2300 GDDs are zoned within moderately suitable regions. This zone cannot be expected to produce yields as high as those in Dezful or Arzuiyeh counties (Orazizadeh 1997, Javaheri et al. 2006). The highest yields can be expected from the southwest regions of South Khorasan province followed by the south of Razavi Khorasan, and the east, west, and south of South Khorasan, respectively (Figure 4).

Crop biomass productivity index (CBPI)

Figure 5 depicts the zoning map showing >75% probability of the occurring CBPI from sowing to harvest in Razavi Khorasan and South Khorasan provinces. Regions where this index is <1750 units are not appropriate for autumn-sown sugar beet. The regions where this index is higher total growth-suitable temperatures are greater during the growing season and the potential is higher for dry matter accumulation. So, these regions are suitable for autumn sowing of sugar beet. These conditions can be found in southern parts of Dargaz county, northern parts of Quchan and Chenaran counties, and a narrow strip in the center of Razavi Khorasan province (Figure 5).

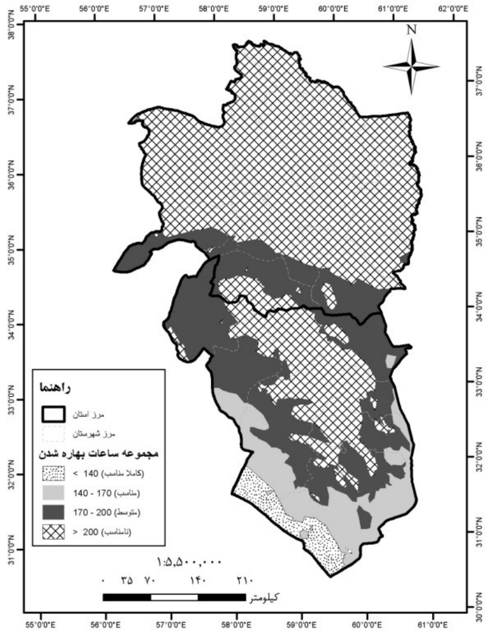

Figure 6. The zonation map depicting <25% probability of the occurrence of total vernalization hours from sowing to harvest in Razavi Khorasan and South Khorasan provinces

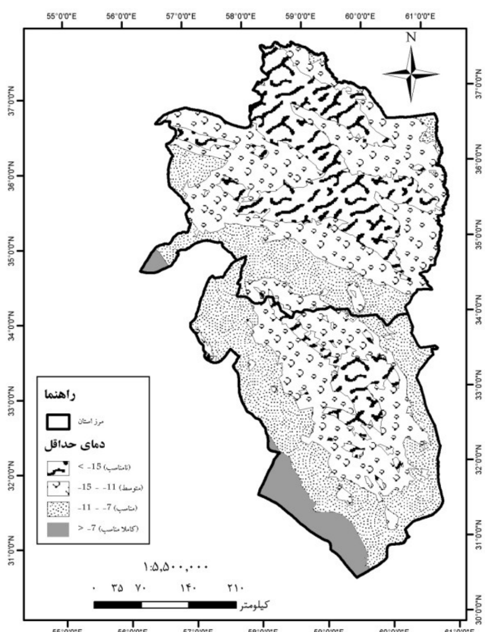

Figure 7. The zonation map depicting <25% probability of the occurrence of freezing temperatures (°C) from sowing to harvest in Razavi Khorasan and South Khorasan provinces

Vernalization

Figure 6 shows the zoning map of <25% probability of occurring total vernalization hours in the studied regions. Sugar beet cultivars reach vernalization threshold only in small parts in the south of South Khorasan where they receive fewer than 140 hours of effective chilling. These regions are faced with low risk of bolting and are very suitable for autumn sowing of sugar beet. Suitable regions are those where the plants experience up to 170 hours of vernalization during their growth period. These conditions can be found in the south of South Khorasan. These lands can be planted with bolting-tolerant cultivars. In regions with over 200 hours, even resistant cultivars will vernalize and bolt. Thus, it is recommended to use very resistant cultivars, which need long days for bolting in these regions.

Freezing

In addition to bolting, survival through winter freezing temperatures is another challenge for the development of autumn-sown sugar beet. In this study, we calculated <25% probability of the occurrence of freezing temperatures in terms of °C from sowing until harvest for each individual station. Then, its digital map was drawn by the derived equation (Table 2) in GIS medium (Figure 7).

The perfectly suitable regions are located in zones where it is >75% likely for the temperature not to fall below -7°C during the growing season. Parts of the regions in the south of Bardaskan, Nehbandan and Birjand counties are among these regions where autumn-sown sugar beets will not be challenged by freezing. The suitable regions included the east, west and south of South Khorasan province, south of Razavi Khorasan province, and small parts in the northeast of Sarakhs county and the west of Sabzevar county. Sugar beet can be sown in autumn in these regions where chilling damage is reversible, although it can influence yield negatively. Regions where it is >25% likely for the temperature to fall below -15°C (most central parts in the two studied provinces) pose a high risk for autumn sowing of sugar beet so that the crop will be severely and irreparably injured if temperatures fall below -15°C. Perfectly suitable and suitable regions can be recognized in Figure 7.

Day length

Figure 8 depicts the map of day length (in hours) two weeks before sugar beet harvest in Razavi and South Khorasan provinces. Regions where day length is shorter than 13 hours, are less challenged by bolting risk. Bolting-resistant cultivars can be grown in these regions. As day lengthens, the risk of bolting gradually increases so that if sugar beet vernalizes during growing season, it can readily bolt. So, regions where day length is over 15 hours, should be sown with cultivars that are very resistant to bolting.

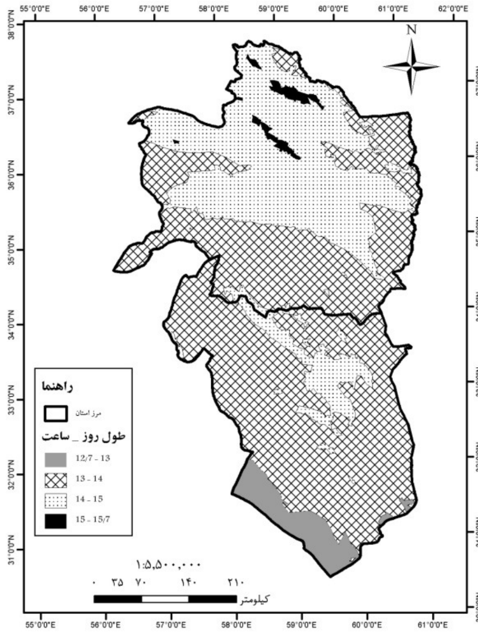

Figure 8. The map of day length (hours) two weeks before harvest in Razavi Khorasan and South Khorasan provinces

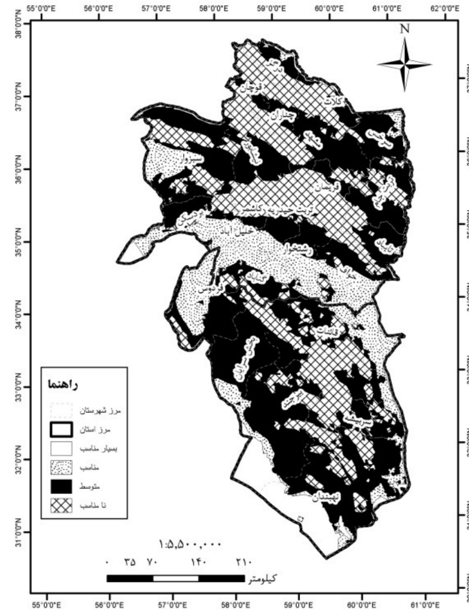

Figure 10. The zonation map of regions prone to autumn sowing of sugar beets in Razavi Khorasan and South Khorasan provinces

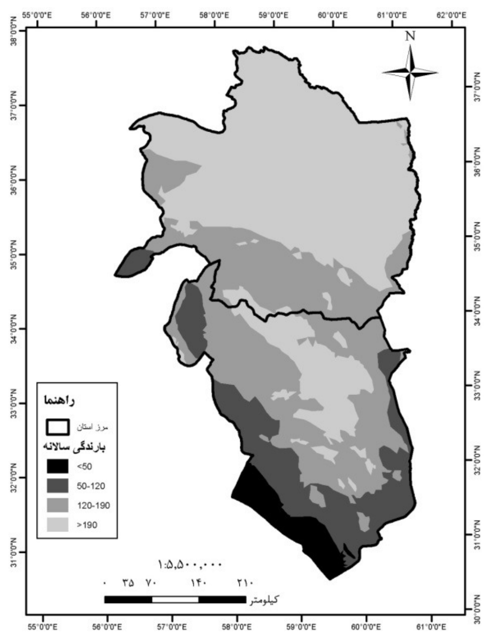

Figure 9. The zonation map of total precipitation (mm) from sowing to harvest in Razavi Khorasan and South Khorasan provinces

Rainfall

Figure 9 displays the zonation of rainfall from sowing to harvest in the studied provinces. The southeast of South Khorasan province that is a very desirable region for autumn-sown sugar beet has the least rainfall, so it is considered unsuitable for autumn sowing. Regions where it is >75% likely for the rainfall to exceed 190 mm over the growing season are categorized as perfectly suitable regions and sugar beets are faced with the risk of vernalization and freezing. If we place more importance on rainfall, then zones, where rainfall is greater than 50 mm, should be paid more attention. These zones that are more appropriate due to their higher precipitation and lower risk of vernalization and freezing are mostly located in the south and southeast of North Khorasan province and in the west and east of South Khorasan province (Figure 9). The area and percentage of precipitation classes are presented in Table 2.

Zonation of susceptible regions

The very suitable regions for autumn-sown sugar beet merely constitute 5% of total area of Razavi and South Khorasan provinces. These regions mostly cover parts of southwest and southeast of South Khorasan province (Table 4). In Razavi Khorasan province, just a part of southwest of Bardaskan county is very suitable for autumn sowing of sugar beet (Figure 10).

Suitable regions, which have an acceptable risk for autumn sowing of sugar beet but their yield and white sugar yield potentials are lower than the very suitable regions, are located in parts of Sabzevar county, northeast of Sarakhs county, and a strip in the south of Razavi Khorasan province. As well, most parts of the west of South Khorasan province are among the suitable regions (Figure 10). Lands moderately suitable for autumn sowing of sugar beet cover most parts of Razavi Khorasan

Table 4. The susceptibility of the lands in Razavi Khorasan and South Khorasan provinces for autumn sowing of sugar beet

Rate of susceptibility	Susceptibility (%)	Area (km^2)
Very appropriate	4.90	9964.25
Appropriate	16.74	34176.13
Moderately appropriate	47.98	97945.69
Inappropriate	30.38	62013.88

province and the parts near the center and west of South Khorasan province (Figure 10).

Results showed that autumn sowing of sugar beet is feasible in most parts of the studied regions in a condition of planting resistant or tolerant cultivars to bolting. Given the high number of sugar factories in Razavi and South Khorasan provinces, autumn sowing of sugar beet will improve the productivity of these factories and will create job opportunities. To develop autumn sowing of this crop in regions with high risk, it is imperative to breed bolting-resistant cultivars. One major application of this zonation is the generalization of the results of the present study and pilot studies (on the basis of bolting and root quantitative and qualitative traits) to zones with similar conditions to the studied regions.

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