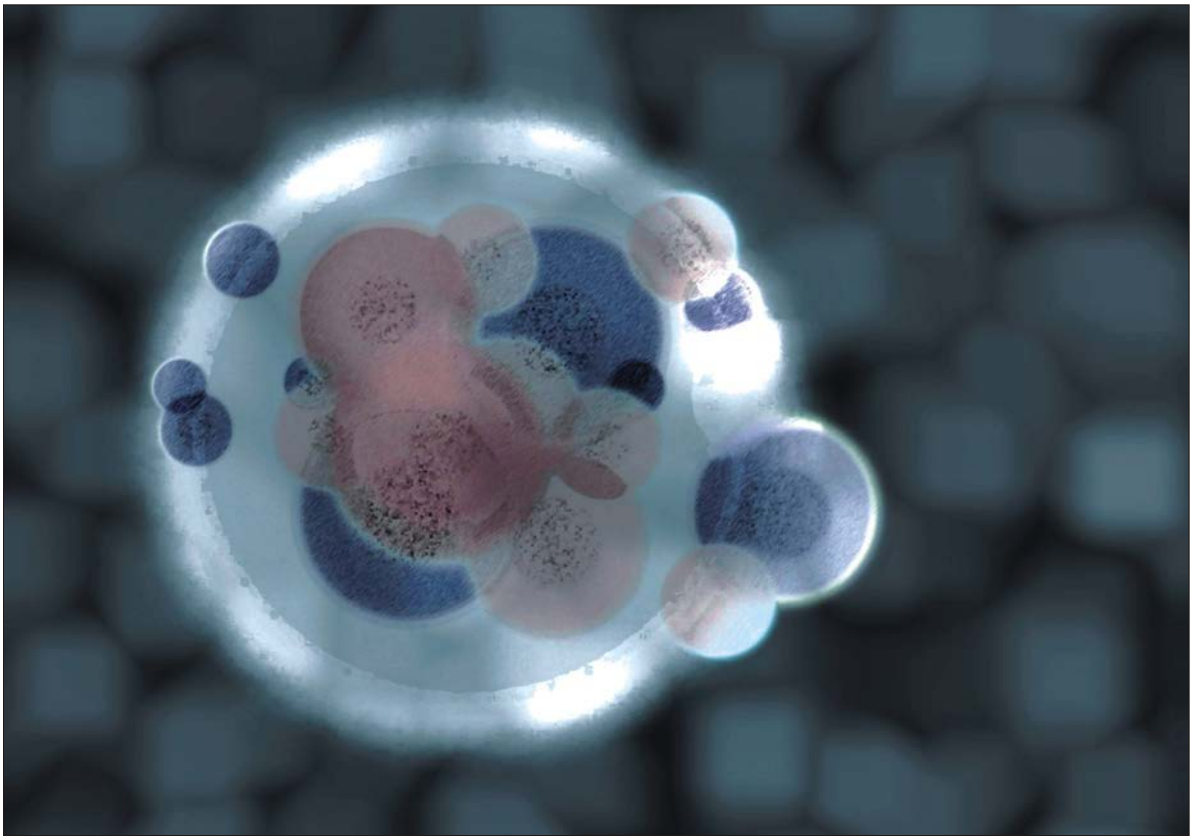

Journal of Biological Sciences

ISSN 1727-3048

Journal of Biological Sciences 8 (2): 298-305, 2008
ISSN 1727-3048

Agro-Ecological Zoning and Potential Yield of Saffron in Khorasan-Iran

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Abstract: In order to zonation and evaluate potential yield of saffron at agroecosystem level in Khorasan Province, Iran, a study was conducted during 2001 and 2002 years, in four selected locations including Birjand, Qaen, Gonabad and Torbat-Haydarieh, which are the main Saffron producing areas in Iran. Data were collected from 160 saffron farms, aged between 1 and 5 years. The obtained data were analyzed statistically and distribution maps were produced using GIS procedure. Results showed that age of saffron farms was the most important factor influencing yield, contributing exceedingly in all fitted regressions for yield in each location. According to the normal frequency distribution curves, yield was varying, at 95% probability, from 0.16 to 7.76 kg ha^{-1} between evaluated fields, with an average equal to 3.96 kg ha^{-1}. The highest frequency of first irrigation was from 17 October to 1 November and the first flowers were rising from 2 to 21 November more frequently. The five years aged farms had the longest flowering period and there was a positive linear relation between continuance of flowering and yield. The Longest irrigation interval was for Gonabad (24 days) and the shortest was for Torbat-Haydarieh (12 days). The farms in Torbat-Haydarieh had the highest actual yield, which is an indication of better farm management in comparison with other areas. In average, the most of farms yielded about 4 kg ha^{-1}, however there were many farms with more than 7 kg ha^{-1} saffron yields.

Key words: Zonation, GIS, farm age, flowering, manure, irrigation interval

INTRODUCTION

Saffron is an important food additive with a long history of consumption (Douglas and Perry, 2003; Zohary and Hopf, 1994). This delicate spice is very expensive and most of its production, processing and packing practices, which are based on indigenous knowledge, are still conducted by hand (Koocheki, 2004). The labor-intensive production of saffron is the main reason for reduction of its cultivation area in many parts of the world, including Spain, Italy and Greece (Negbi, 1999). Iran is the first saffron producing and exporting country worldwide and in the past 30 years, the acreage and production of saffron has increased by 16 and 9 times, respectively.

Saffron is an important cash crop in Southern Khorasan province, which is mainly managed by family-labor and cooperation of local communities. Thus, saffron is not simply a source of income, but it is also a product which promotes social and cultural collaboration (Kafi *et al*., 2002). In recent years, researches have also offered new horizons and opportunities for utilization of saffron in medicine and industry. For example, some scientific findings has motivated hopes for treating cancer using saffron (Nair *et al*., 1991; Abdullaev and Frenkel, 1999).

Saffron is an important economic crop in smallholder rural communities and there is a lot of studies about agronomic aspects of its production at plot level (Kafi *et al*., 2002), but less efforts has been made at agro-ecosystems level to evaluate yield attributes and factors contributing in yield fluctuations. The purposes of present investigation were:

- To evaluate biophysical, agronomic and management factors contributing to yield at farm scale in various areas with different farming practices and climatic condition. For this purpose, all involving factors were analyzed in a statistical manner to find the magnitude of effects of each factor on yield and yield attributing components.
- To find out the association between phenological scales and flower inducing factors such as gradient of temperature in surveyed region, from Torbat-haydarieh in north to Birjand in south, which is the main center of saffron production in Iran.
- To analyze yield attributes using GIS to obtain appropriate maps respecting yield fluctuations based on farm practices, temperature gradient and phenological stages.

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MATERIALS AND METHODS

Saffron producing area of Southern Khorasan, in which 95% of Iran's saffron is produced, was investigated in four main counties, including Birjand, Qaen, Gonabad and Torbat-haydarieh, during two growing seasons of 2001 and 2002. One hundred and sixty saffron fields, which differed widely in size (500 m^2 to 2 ha), age (1 to 5 years), farming practices (depended on farmers skills) and farming history, were chosen. A comprehensive survey, by consulting with farmers and direct monitoring, was made during two years on yield attributes and its relations with some measures such as date of planting, time of first irrigation, time of flowering start, flowering period, the amount of applied manure, irrigation frequency (including summer irrigation if any), size of corm and planting method.

Climatic data were collected from the nearest weather station. The relation between yield and attributing factors was analyzed statistically and correlation coefficients were calculated accordingly. Farming practices and phenological stages of plant, particularly appearance time of first flowers and length of flowering period were also correlated to farming practices such as time of irrigation and corm size for the whole area.

Finally, appropriate maps were prepared based on GIS to show gradient of yield fluctuations in association with farming practices, temperature gradient and phenological stages (start and length of flowering). Statistical analyses were done using Excel, Slide Write, Sigma Stat and SPSS softwares. For maps to be drawn, Arc info, Ilwis and ArcGIS were used.

RESULTS AND DISCUSSION

Among all four counties and in average between farms with different ages, Torbat-haydarieh and Gonabad, which are respectively located in northern and central part of saffron belt, had the highest and the lowest yields (dried stigmas), respectively (Table 1). Region-wide, it is observed that one-year aged saffron farm produce low yields, with gradual increase in consequent years, up to the 4-5 years. This finding has been confirmed by other studies (Behnia, 1991; Sadeghi, 1993; Abrishami, 2004). However, yields up to 10 kg ha^{-1} in the first year and 8 kg ha^{-1} in the subsequent year have been reported in Spain (Kafi *et al*., 2002).

Normal distribution of yield showed that saffron yields varied from 0.16 to 7.76 kg ha^{-1} ($p<0.05$) in whole area, with an average of 3.96 kg ha^{-1} (Fig. 1). In Kashmir, average yield of saffron under rainfed condition has been reported to be 2-3 kg ha^{-1}, rising up to 9 kg ha^{-1} with irrigation (Munshi, 1994). In other parts of world, the mean reported yields is 2-2.5 kg ha^{-1} for Morocco and

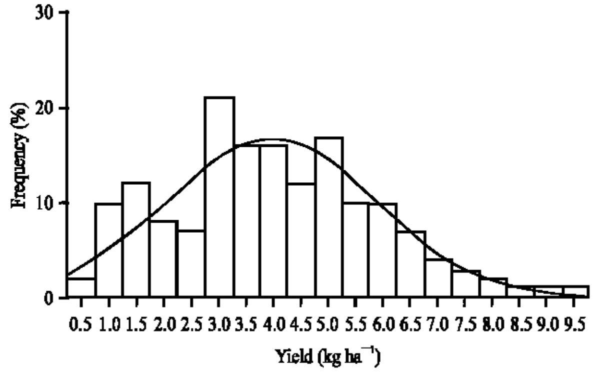

Fig. 1: Normal distribution function for yield in the total area

Table 1: Yield of saffron in different farm age in four counties (kg ha^{-1})

	Age of farm					
Counties	1st year	2nd year	3rd year	4th year	5th year	Mean
Birjand	1.250	1.887	2.843	5.668	6.300	3.590
Qaen	3.125	5.750	4.580	4.810	5.462	4.309
Gonabad	0.825	1.656	3.100	3.618	4.206	2.681
Torbat-haydarieh	2.975	3.192	5.020	6.500	7.937	5.270
Mean	2.043	3.076	3.885	5.149	5.976	3.962

Table 2: Yield prediction functions for each county, based on different attributing factors

Counties	Function	R^2
Birjand	Yield = 0.408+(0.731×age of farm)+ (0.0415×start of flowering)+(0.0479×manure)-(0.0229×irrigation interval)	0.96
Qaen	Yield = 2.76+(0.497×age of farm)+ (0.0197×manure)-(0.0316×corm size)	0.90
Gonabad	Yield = 0.329+(0.875×age of farm) +(0.0496×start of flowering) - (0.0404×irrigation interval)	0.90
Torbat-haydarieh	Yield = 1.29+(0.662×age of farm)+ (0.141×flowering period)+ 0.0361×manure) - (0.0206×nitrogen)	0.95
Total area	Yield = 0.408+(0.731×age of farm)+ (0.415×start of flowering)+ (0.0479×manure) - (0.229×irrigation interval)	0.95 0.87

1: Age of farms from 1 to 5 years. 2: Date of flowering is counted from date of first irrigation as start point. 3: Manure and in some cases nitrogen fertilizer, was applied on the basis of ton ha^{-1} and kg ha^{-1}, respectively. 4: Irrigation intervals are 12, 18 and/or 24 days. 5: Weight of corm on the base of gram. 6: Yield means kg ha^{-1} of dried stigma

10-17 kg ha^{-1} for Italy (Douglas and Perry, 2003), 4.3 kg ha^{-1} for Greece (Goliaris, 1999) and 24 kg ha^{-1} in New Zealand under experimental condition (McGimpsey *et al*., 1997).

Based on calculations, it is appeared that farm age accounts for most of yield variation between surveyed farms (Table 2). As the five years old farms produced the highest yield in all counties (Table 1), yield variation for these farms was monitored by GIS system for whole area (Fig. 2). Torbat-haydarieh in northernmost and Birjand in southernmost of this saffron belt had the highest yields and yields in Gonabad, which is located between these limits, rarely exceed from 5 kg ha^{-1}.

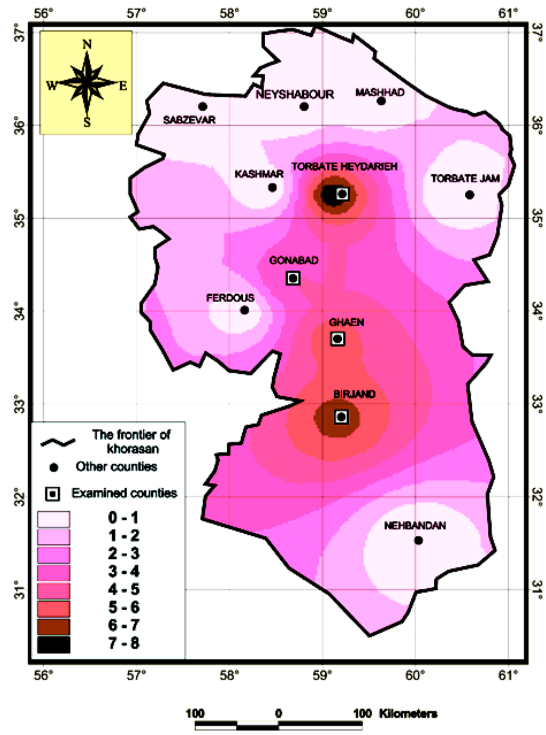

Fig. 2: Pattern of saffron mean yields in five years old farms (kg ha^{-1})

Table 3: The frequency of first irrigation and start of flowering in different dates for four counties (%)

	Birjand		Qaen		Gonabad		Torbat-h.		Total Area	
Date	First irrigation	Flowering start	First irrigation	Flowering start	First irrigation	Flowering start	First irrigation	Flowering start	First irrigation	Flowering start
3-7 Oct			2.5				15.0		4.38	
8-12 Oct.			10.0		2.5		30.0		10.63	
13-17 Oct.	5.0		10.0		17.5		22.5		13.75	
18-22 Oct.	12.5		17.5		26.0		10.0		16.25	
23-27 Oct.	35.0	5	32.5	5.0	17.5	5.0	12.5	20.0	24.38	7.75
28 Oct.-1 Nov.	27.5	10	22.5	5.0	24.0	10.0	5.0	37.5	20.00	15.63
2-6 Nov.	20.0	20	5.0	10.0	12.5	27.5	5.0	15.0	10.63	18.13
7-11 Nov.		40		32.5		22.5		15.0		27.50
12-16 Nov.		20		30.0		15.0		7.5		16.88
17-21 Nov.		5		15.0		12.5		2.5		10.00
22-16 Nov.				2.5		7.5		2.5		3.13

There was an extent range for applying the first irrigation by farmers in different locations, which was led to different times of flowering start (Table 3). In Torbat-haydarieh, 15% of farms were irrigated between 3-7 October (4.4% for whole area), whereas only 2.5% of farms in Qaen were irrigated in period and no irrigation in Birjand and Gonabad until 12 October (Table 3). It seems date of first irrigation is closely reconciled with thermal regime of the area. Low temperature is an important factor in flowers appearance (Behdani *et al*., 2004; Milyaeva and Azizbekova, 1987; Molina *et al*., 2004). Long-term mean temperature in Oct. is 14.8°C for Torbat-haydarieh and 16.8°C for Birjand (Table 4). In the whole area, 24.4% of farms were irrigated during 23-27 Oct., the highest frequency between all dates; however more farms were irrigated in Birjand and Qaen during same period (Table 2). The highest frequency of the first irrigation for Gonabad was 26% at 18-22 Oct and for Torbat-haydarieh it was 30% at 8-12 Oct (Table 3). This changing trend of doing first irrigation follows declining trend of temperature during flowering period (from October to November) from Birjand to Torbat-haydarieh (Table 4).

In average between all locations and farms, the maximum frequency of flower appearance occurred during 7-11 Nov. The pattern of flowering appearance, with a 2-3 weeks delay, followed general trend of applying the first irrigation. In the other words, the highest appearance frequency of flowers for each county was occurred 2 weeks after the first irrigation (Table 3, Fig. 3, 4), with

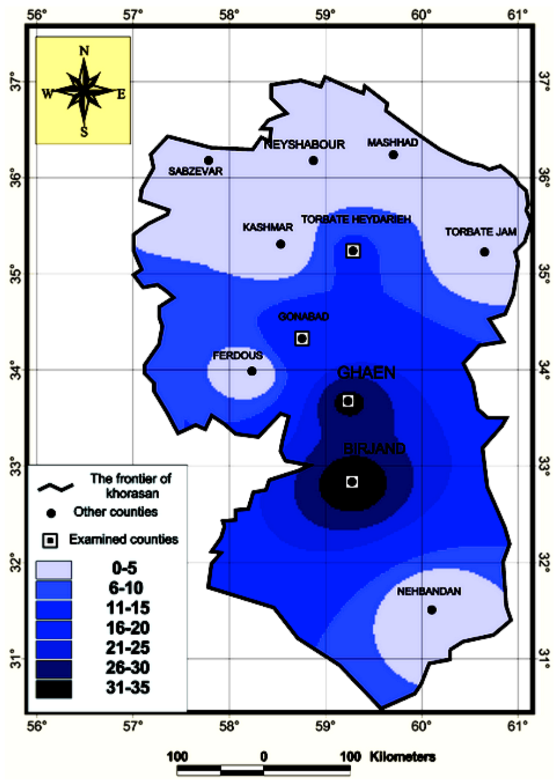

Fig. 3: The frequency of applying first irrigation at 23-27 Oct. in different counties (%)

Table 4: Long term mean temperature in four counties (°C)

	Counties			
Months	Birjand	Qaen	Gonabad	Torbat-h
Jan.	4.4	2.4	3.46	1.2
Feb.	6.5	4.1	5.90	3.2
Mar.	11.3	8.5	10.70	8.1
Apr.	17.0	15.0	16.95	14.6
May	21.9	19.4	22.62	19.8
Jun.	26.4	23.4	26.94	24.7
Jul.	27.6	25.0	28.05	26.7
Aug.	25.8	22.9	26.35	25.0
Sep.	22.0	18.9	22.66	20.8
Oct.	16.8	13.6	17.18	14.8
Nov.	10.8	9.3	10.69	8.8
Dec.	6.3	5.4	5.52	3.8

more delay in Torbat-haydarieh (Table 3, Fig 5). These findings are in agreement with Kafi *et al*. (2002) and Molina *et al*. (2004) who reported the onset of saffron flowering is happened between 2-3 weeks after first irrigation. Because time of firs irrigation is the most important factor in initiation of flowers emergence in saffron, the timing of irrigation is so important with regard to labor-intensive picking of saffron. In large-sized saffron farms, irrigation of different parts of farm should be split to stimulate gradual flower emergence in each segment, in order to facilitate daily picking of flowers with available work force.

The longest Flowering period among different counties equal to 20-25 days was found in Torbat-haydarieh, which also had the highest mean yield (Table 1, 5). About half of farms in this county were benefited from prolonged flowering period, which offer a proper opportunity to farmers, to manage better flower picking during harvest time. In the other words, as daily flower picking put considerable pressure on labor requirements, therefore prolonged flowering period will cause farmers to be release from this tension and also more yield to be produced (Fig. 6, 7). In general, dependent on minimum temperature and time of first irrigation, October,

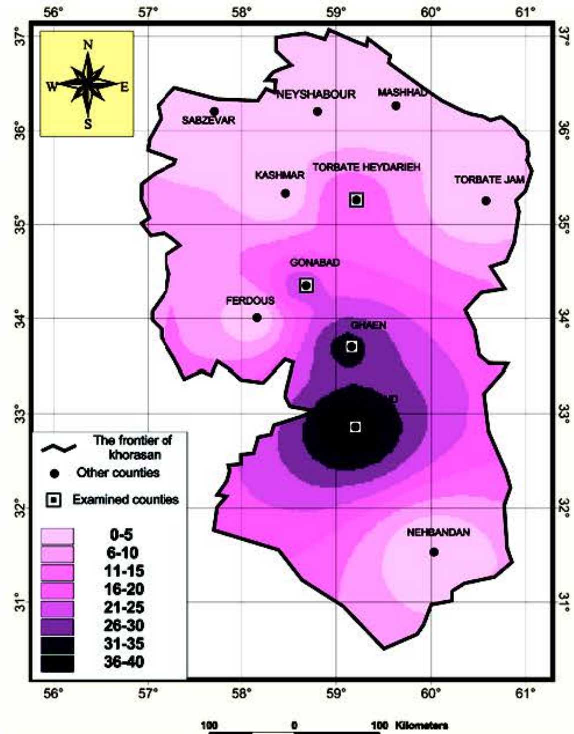

Fig. 4: The frequency of start of flowering (first flowers appearance) at 7-11 Nov. in different counties (%)

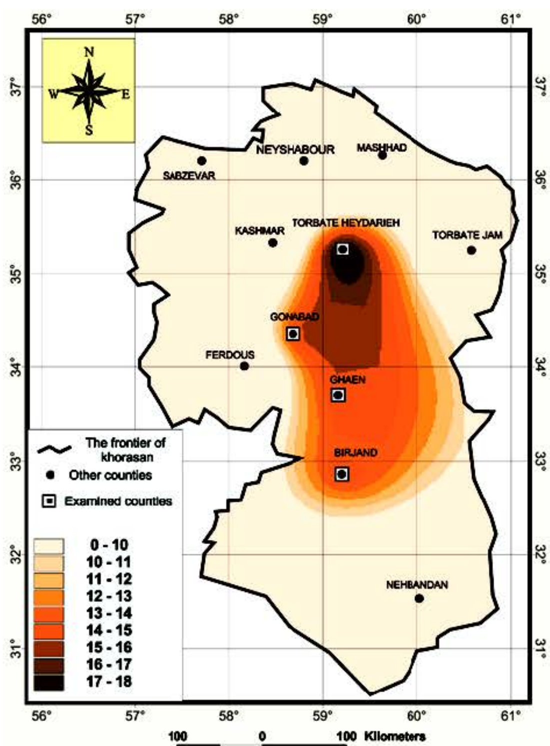

Fig. 5: Time lag between dates of first irrigation and first flowers appearance in different counties (day)

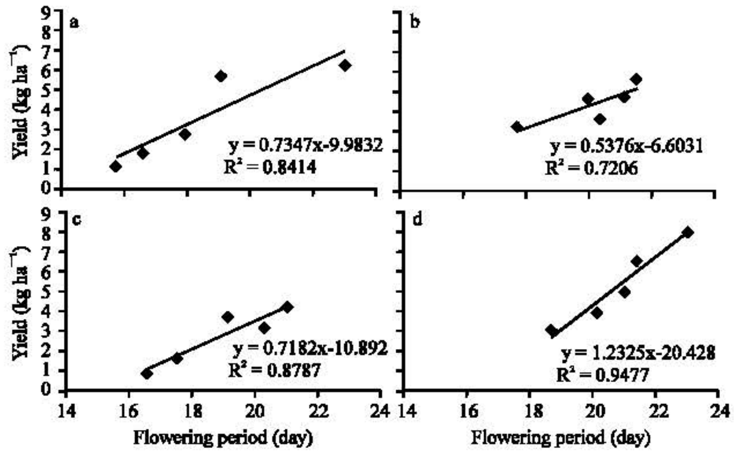

Fig. 6: Relation between yield and length of flowering period in different counties, including Birjand (a), Qaen (b), Gonabad (c) and Torbat-haydarieh (d)

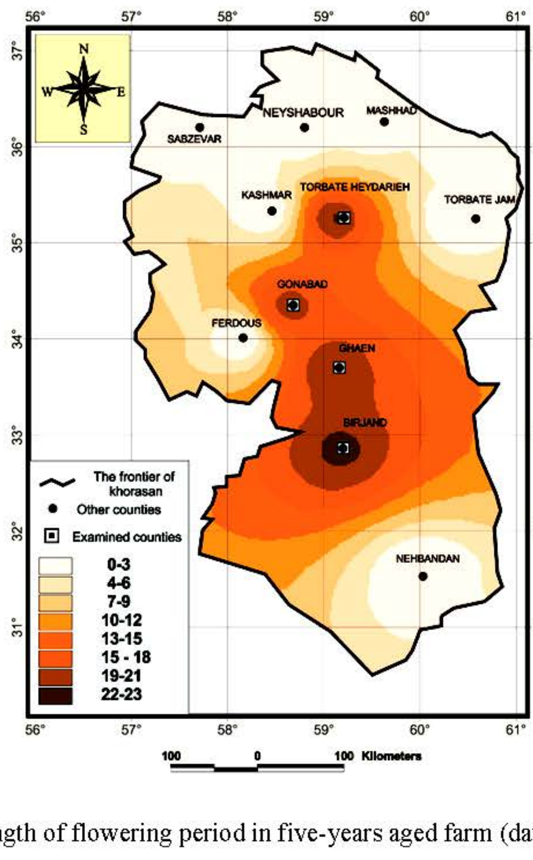

Fig. 7: Distribution pattern of length of flowering period in five-years aged farm (day)

Table 5: The frequency of length of flowering period for different counties (%)

	Length of flowering period			
Counties	10-15 day	16-20 day	21-25 day	26-30 day
Birjand	20.00	52.50	22.50	5.00
Gaen	2.50	52.50	42.50	2.50
Gonabad	10.00	60.00	25.00	5.00
Torbat-haydarieh	2.50	47.50	47.50	2.50
Total	8.75	53.125	34.375	3.75

November and December consists flowering period for this area, with the most frequency occurred in Nov. Considering the long-term climatic data, it is appear that the mean of minimum temperature in Nov. is lower for Torbat-haydarieh than other locations (Fig. 8). However, there are some reports (Molina *et al*., 2004) asserting that the optimum temperature required for flower appearance

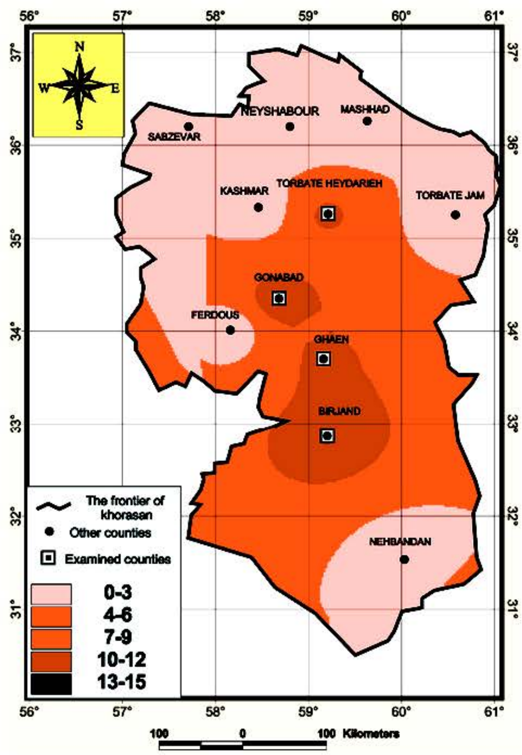

Fig. 8: Distribution pattern of mean temperature in Nov. in different counties (°C)

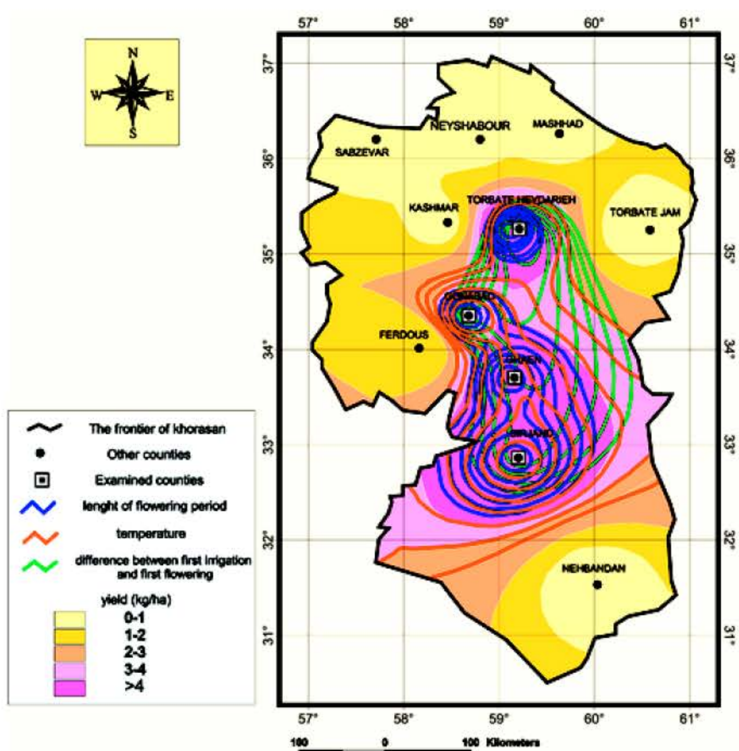

Fig. 9: Trend of yield variation in relation to difference between dates of first irrigation and appearance of first flowers, length of flowering period and temperature

is different from the required temperature for flower initiation, because flower initiation takes place during summer, whereas flower emergence occurs in autumn, when temperature is declining. We tried to explain variations in yields in this saffron belt in relation to changing pattern of temperature, the length of flowering period and date of first irrigation (Fig. 9). In Torbat-haydarieh, for example, earlier irrigation and therefore earlier flower emergence, which are a consequent of lower mean temperature in this area, are related with higher yields.

CONCLUSION

The timing of first irrigation, which is normally conducted earlier in regions with lower mean temperature during autumn, is a key factor in achieving higher saffron yields. It is also important in respect to the length of flowering period and timing of flowers picking, especially in large farms. It means that early application of first irrigation in appropriate time, with regard to low mean temperatures, is so important for saffron yield, because if the first irrigation be applied earlier, i.e., when mean temperature is still high, vegetative organs (leaf) may also appear earlier than flowers, which is an unusual event in saffron growth. Length of flowering period, which is also related to these factors, is not only effective on yield, but also important for labor requirements in picking flowers. Therefore, labor requirements and length of flowering period are important factors in saffron production.

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