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ORIGINAL PAPER

Variability of growing season indices in northeast of Iran

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Abstract Accurate use of precipitation can be considered as one of the best options to decrease the amount of underground water extraction for agriculture in arid and semi-arid areas such as northeast of Iran. For this reason, characteristics of the growing season such as onset, cessation, and length of the growing period should be analyzed. In this paper, we have calculated growing season characteristics of five locations in northeast of Iran using 45 years historical daily weather data and employed four approaches with different calculation methods. As temperature is one of the limiting factors in irrigation-based agriculture, the first approach has been based on this factor. The three remaining approaches were based on joint rainfall and temperature approach, rainfall, evapotranspiration, and temperature approach, and the final approach was based on availability of adequate water in 0.25 m of soil profile. The calculated onset dates using second and third approaches have been based on soil water balance model and relative evapotranspiration rate, and both were evaluated also to find whether the onset is a false start occurrence or not. The results showed that, when temperature was the only limiting factor, Bojnourd station with 197 days showed the longest growing season, however, when precipitation was used along with temperature, longest growing season (124 days) was obtained for Sabzevar station. The third approach which benefits from a water balance model and is similar to rainfed conditions showed the longest growing season with 147 days for Mashhad station. When adequate soil water approach was used, Bojnourd station with 255 days showed the longest growing season. Evaluation of false start of the growing season indicated the lowest probability of false start occurrence for Mashhad compared with other locations.

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1 Introduction

Seasonal climate variability, notably rainfall variability, results in depressed seasonal agricultural production in rainfed system conditions which mostly rely on rainfall as the main source of required moisture (Tao et al. 2004; Bannayan et al. 2010). Availability of water rather than land is the main constraint on agricultural production in arid and semi-arid environments (Bannayan et al. 2008). Crop production from late spring to the end of the summer months in the semi-arid environment of the Khorasan province in Iran mainly relies on irrigation. Shortage of water in arid and semi-arid parts of this region where annual precipitation is less than 220 mm with almost no rainfall during the summer is a prominent limiting factor of crop production (Khazaie et al. 2008). Agriculture in northeast of Iran is largely rainfed though this region is characterized by high variability in both rainfall and seasonal onset of the rain (Bannayan et al. 2010). Rainfed agriculture system is the main source of staple food production, and it greatly supports the livelihood of the majority of farmers in this region. Farmers sow their plants based on their local knowledge of the beginning of the growing season and rainfall occurrence. The onset of the growing season is a key variable as false starts followed by prolonged dry spells may jeopardize the final crop production (Muchow et al. 1994). Therefore, a less risky planting date would be quite beneficial.

The ability to estimate effectively the start, end, and thus, the length of the growing season is vital to planning of rainfed agricultural activities. To determine the beginning and the end of a growing season, especially for arid conditions, the precipitation should be fairly continuous and sufficient to ensure enough soil moisture at the time of planting, and it is also important to maintain or even increase the level of water as the season advances. To estimate growing season indices based on available water, various studies have employed different approaches. Some studies including those of Ilesanmi (1972) and Nicholls (1984) employed rainfall onset to estimate the growing season indices. Lineham (1983) used a water balance approach in determining the onset and cessation of the growing season. Using all these indices, each season was clustered according to date of rain onset and adequacy of rainfall for the growth of the study crop. Raes et al. (2004) used a soil water balance model to determine the growing season indices in order to optimize planting dates and recommended a certain amount of rain (40 mm) in 4 days criterion. Mugalavai et al. (2008), in a similar way, quantified the growing season indices based on cumulative rainfall depth that will bring the top 0.25 m of the soil profile to field capacity during a maximum of 4 days. Cessation of the growing season was also quantified when water stress in the root zone of the maize crop exceeds a threshold value. In contrast to rainfed production, under irrigated conditions, temperature plays the major role on the growing season length, onset, and cessation determination (Bannayan et al. 2004).

The early start dates of the growing season may be followed by dry spells which may last a week or longer. Benoit (1977) has reminded that early planted crops can suffer stress from a water shortage during a prolonged dry spell, and the optimum sowing is an advantage for higher economic profit. A successful early planting can produce an earlier crop which may have a higher yield (Gimeno et al. 1989), but later planting reduces the risk of early crop failures (Calviño et al. 2003). Sivakumar (1988) has defined the occurrence of the false start as the date which, after that, a 7-day dry spell or more happens in the following 30 days. Raes et al. (2004) have evaluated this criterion using an analysis of the relative transpiration rate (the ratio of the actual transpiration to the crop transpiration) over a 30-day period following sowing (initial growth stage) by means of a soil water balance model. Crop failure due to false start was indicated by a relative transpiration rate of less than 35% over 30 days.

The purpose of this study was to determine a reliable approach for defining the beginning and end of the growing season employing four approaches including, using only temperature, soil water level, combination of both temperature and soil water, and availability of adequate water in the top soil, and to evaluate the probability of a false start occurrence of onset

2 Materials and methods

2.1 Study locations and climate data

Five locations in Khorasan province with varying precipitation characteristics were used in this study (Fig. 1). Table 1 shows the physiocharacteristics of the study locations. For each approach at each location, daily weather data of 1961–2005, obtained from meteorological station in each location, were used for calculations. Daily weather data included the maximum and minimum temperature, precipitation, sunshine hours, and wind speed. The agricultural activities in the study locations are mainly rainfed, however, rainfall is very variable and uncertain. When the farmers cultivate same crops or same variety of any given crop in such locations with variable annual precipitation, final crop yield output would be also quite different across different years.

To measure the water content at field capacity (FC) and permanent wilting point (PWP), 16 undisturbed soil samples (Table 2) across the study locations were collected. Undisturbed soil samples were saturated with distilled water and weighted for calculating the saturation percentage. Then saturated soil samples were carefully transferred to the pressure chamber, and appropriate pressure was applied (−33 kPa matric potentials for FC and −1,500 kPa for PWP). When equilibrium was reached (minimum 24 h) for each pressure and no change was observed in the volume of draining burette, the burette tap was closed and the pressure was released from the chamber. Soil samples were transferred from tubes to a weighing tin, and the moisture content was determined in FC and PWP point.

2.2 Evaluation criteria

2.2.1 Temperature-based approach

Various ranges of temperature as thermal thresholds that different crops would be able to grow and when the growth would cease (Evans 1975) have been considered in this approach. These temperature ranges consisted of 0°C, 5°C, 10°C, and 15°C as the minimum temperatures and 32°C and 36°C as the maximum temperatures. Thus, the start of the growing season based on temperature alone was when, for five consecutive days, the minimum temperature is equal or more than the selected minimum required temperature and the cessation of the growing season would be when, for five consecutive days, temperature is above the maximum selected temperature. All possible combination of the above selected minimum and maximum temperatures, except 15–32°C, were employed in the study (Table 3). The 15–32°C was not considered because there was no locally cultivated crop growth based on this range.

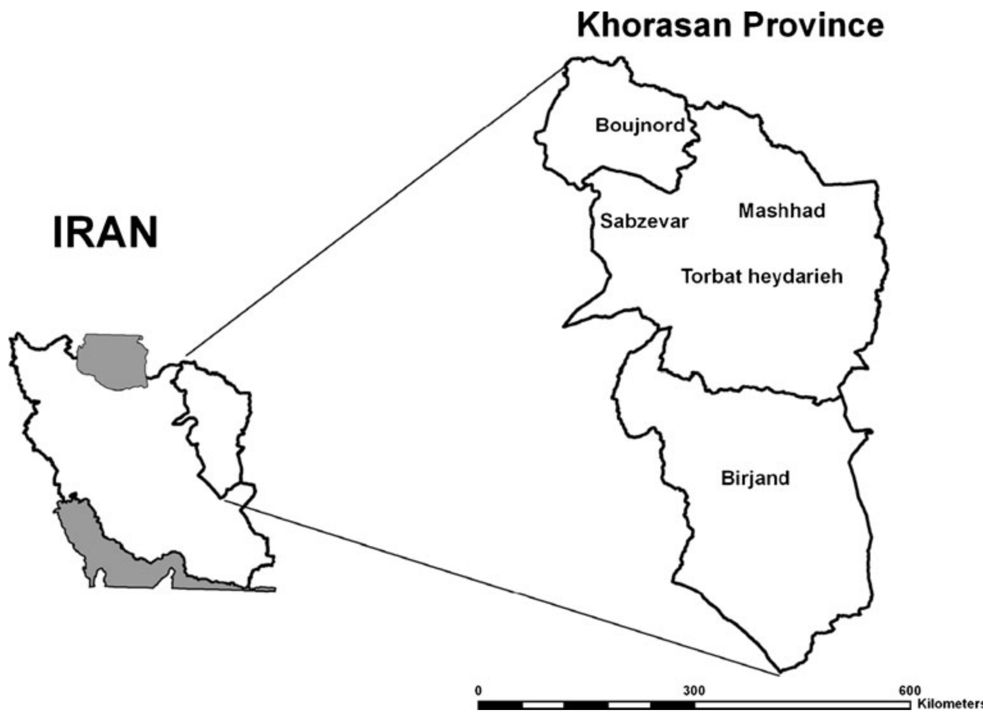


Fig. 1 Study locations in northeast of Iran

As evaluating false start approach requires the rainfall and this approach do not account for the rainfall in its calculation, so this approach was not evaluated for the occurrence of false start.

2.2.2 Temperature and rainfall approach

Same combination of temperatures employed in previous approach were used to calculate the growing season indices plus a precondition criterion based on rainfall. Every daily weather data of each year was searched for rainfall amount at each location. When the accumulated rainfall for five consecutive days was equal or more than water content at FC measured at each location, then, the next step in the algorithm was looking at minimum and maximum temperature and followed the first approach to calculate the onset and cessation of the growing season. In this approach, the cessation of the growing season is like the first approach and would be when, for five consecutive days, the maximum temperature is more than selected threshold.

2.2.3 Temperature-, rainfall-, and potential evaporation-based approach

To determine the growing season indices based on available water, various approaches have been employed in different regions. Benoit (1977) defined the onset date for northern Nigeria as the date when accumulated daily rainfall exceeded 0.5 of the accumulated potential evapotranspiration for the remainder of the season, provided that no dry spell longer than 5 days occurs immediately after that date. Kowal and Knabe (1972) defined the onset date as 10 days in which precipitation is equal to or greater than 25 mm. In this study, a cumulative rainfall depth that will bring the top 25 cm of the soil profile to field capacity during a maximum of 4 days was considered for required calcula-

Table 1 Long-term annual average of minimum temperature (*T*min), maximum temperature (*T*max), precipitation, and sunshine hours of study locations

Region	Latitude (N)	Longitude (E)	Elevation (m)	*T*min (°C)	*T*max (°C)	Precipitation (mm)	Total sunshine (h)	Database period
Mashhad	36° 18′	59° 36′	1015	7.1	21.1	255.2	2892.4	1961–2005
Sabzevar	36° 13′	57° 42′	917	10.6	24.2	188.6	3024.5	1961–2005
Torbate heydarieh	35° 16′	59° 13′	1451	7.3	21.3	274.8	3156.3	1961–2005
Birjand	32° 53′	59° 13′	1491	8.4	24.5	170.8	3225.7	1961–2005
Bojnourd	37° 28′	57° 19′	1066	6.8	19.7	272.4	2714	1977–2005

Table 2 Typical soil characters of study locations

Region	Sand (%)	Silt (%)	Clay (%)	Soil texture	OC (%)	FC	PWP	Bulk density (g cm^{-3})
Mashhad	36	34	30	Clay loam	0.06	24	10.7	1.3
Sabzevar	45.8	32	22.2	Loam	0.62	18.2	8.3	1.30
Torbate heydarieh	55.8	26	18.2	Sandy loam	0.53	20	9.3	1.35
Birjand	46	30	24	Loam	0.33	18.53	8.5	1.35
Bojnourd	43.8	36	20.2	Loam	0.21	26.8	12.1	1.30

tion. In this approach, the available water was calculated as the difference between daily potential evaporation and any occurred rainfall. The available water was accumulated, and when this amount of water would be equal to water content at FC, then it is considered as the onset of the growing season. In other words, in this approach, the rainfall considered as input and potential evaporation as the output of the system. Cessation of the growing season was considered when the observed maximum temperature for five consecutive days is more than the 36°C.

To determine the amount of rainfall (*P*) required to raise the soil moisture to desired level, the total available soil

Table 3 Growing season length across all five locations based on temperature approach

Region	Temperature range (°C)						
	0–32	0–36	5–32	5–36	10–32	10–36	15–36
	Q_0						
Bojnourd	70	75	43	44	13	16	1
Mashhad	72	75	39	43	3	13	1
Sabzevar	66	66	19	32	5	10	1
Torbat Heydarieh	67	75	43	44	7	18	1
Birjand	60	62	32	43	4	3	1
	Q_1						
Bojnourd	97	105	59	65	27	34	3
Mashhad	89	93	57	67	35	43	1
Sabzevar	83	98	38	55	18	29	3
Torbat Heydarieh	83	100	59	66	28	40	4
Birjand	91	96	53	58	26	32	1
	Q_2						
Bojnourd	106	112	67	80	38	51	6
Mashhad	103	110	72	81	43	50	4
Sabzevar	98	108	58	68	29	40	8
Torbat Heydarieh	101	110	64	75	40	47	11
Birjand	103	104	68	71	36	44	3
	Q_3						
Bojnourd	126.5	130	83.5	91	48	57	15
Mashhad	123	129	87	90	52	56	14
Sabzevar	111	124	68	80	39	50	21
Torbat Heydarieh	111	130	74	86	46	57	20
Birjand	117	127	77	85	51	53	8
	Q_4						
Bojnourd	167	197	112	122	82	93	35
Mashhad	143	167	119	119	97	96	37
Sabzevar	135	154	104	102	68	70	59
Torbat Heydarieh	149	157	91	132	60	88	48
Birjand	145	155	122	134	95	95	48

water (TAW) for the major soils of the study locations were determined using soil water amount at both FC and PWP. Reference evapotranspiration was calculated based on Penman–Monteith equation and the required data obtained from meteorological stations.

2.2.4 Availability of adequate water percentage approach

In this approach, total available water (TAW, in millimeters) were calculated according to Eq. (1) for 25 cm of the soil profile and readily available soil water (RAW, in millimeters) as 40% of TAW were assumed as adequate water amount for growth of different crops during the initial growth stage. RAW amount (40% of TAW) was chosen based on local farmers' knowledge.

$$TAW = 1000^{*}(FC - PWP)^{*}0.25 \tag{1}$$

Then, the daily percentage of the adequate water was calculated by dividing the daily rainfall to RAW. In this study, the 24th of September was assumed as the first day of a year as the average sowing date of rainfed crops across the study locations. This assumption was based on local farmers' indigenous knowledge. The first day with probability of at least 15% of having adequate water in 25 cm of soil profile was considered as the onset day of the growing season and the last day with probability of less than 15% of adequate water as the cessation of the growing season. The chosen probability was arbitrary and can be changed based on the economic value of the crop or farmer risk acceptance. Similar to Mugalavai et al. (2008), to avoid negative length of the growing season, the difference between the earliest cessation and latest onset was set at minimum of 10 days. The results are shown in Figs. 2, 3, and 4. This approach provides only one onset day for a period for every probability level, so these results were not evaluated for the false start occurrence.

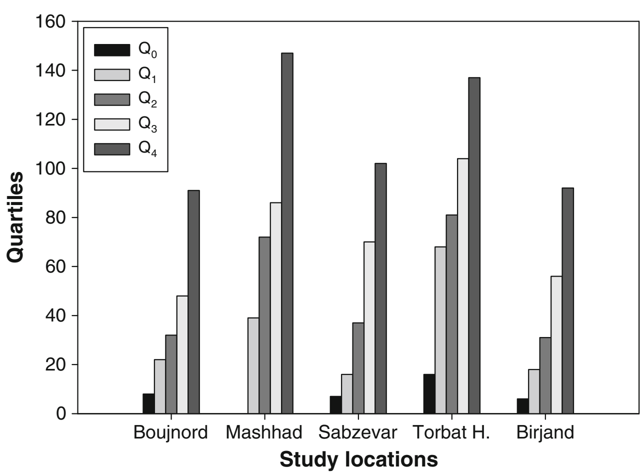


Fig. 2 Growing season length across all five locations based on water balance approach

2.3 Evaluation of the onset date

The ratio of the adjusted evapotranspiration (ET_{adj}) to crop evapotranspiration (ET_c; Allen et al. 1998) was used as relative evapotranspiration index which quantifies the degree of satisfaction of the crop water requirements. This index which is strongly correlated with crop yield (Augustine and Yao 1974) has been applied in the present study to detect occurrence of false start. This index varies from 0 as when the outgoing water amount from the soil is equal to TAW, to 1 when there is no water stress. This index is based on the soil water balance model (Raes et al. 2004). To distinguish that the onset date is a false start or not, this index should be consistent for a period of 30 days (assumed as an average length of the initial growth stage of an annual crop), and after this period, if the mean of this value is less than 0.35, it was considered as false start (Raes et al. 2004).

For this purpose, the soil water content in the top soil (25 cm of soil profile) was determined at each day by considering the incoming (rain) and outgoing (soil evaporation and crop transpiration) water fluxes. The wheat crop was considered in this study since it is the staple food of the majority of people and has the highest cultivation area under rainfed condition compared with other crops in Iran. In the next step, total available water TAW (millimeters) was calculated for 25 cm of soil profile for every location based on Eq. 1. Crop coefficient (Kc) at initial growth stage of winter wheat was selected as Kc=0.7 (Allen et al. 1998). Depletion factor, p, (fraction of TAW that a crop can extract from the root zone without suffering water stress) was assumed as 0.55 for winter wheat when ETc is 5 mm day^{-1} (Allen et al. 1998). When ETc differed from 5 mm day^{-1}, p was adjusted using Eq. (2):

$$p = 0.55 + 0.04(5 - ETc) \tag{2}$$

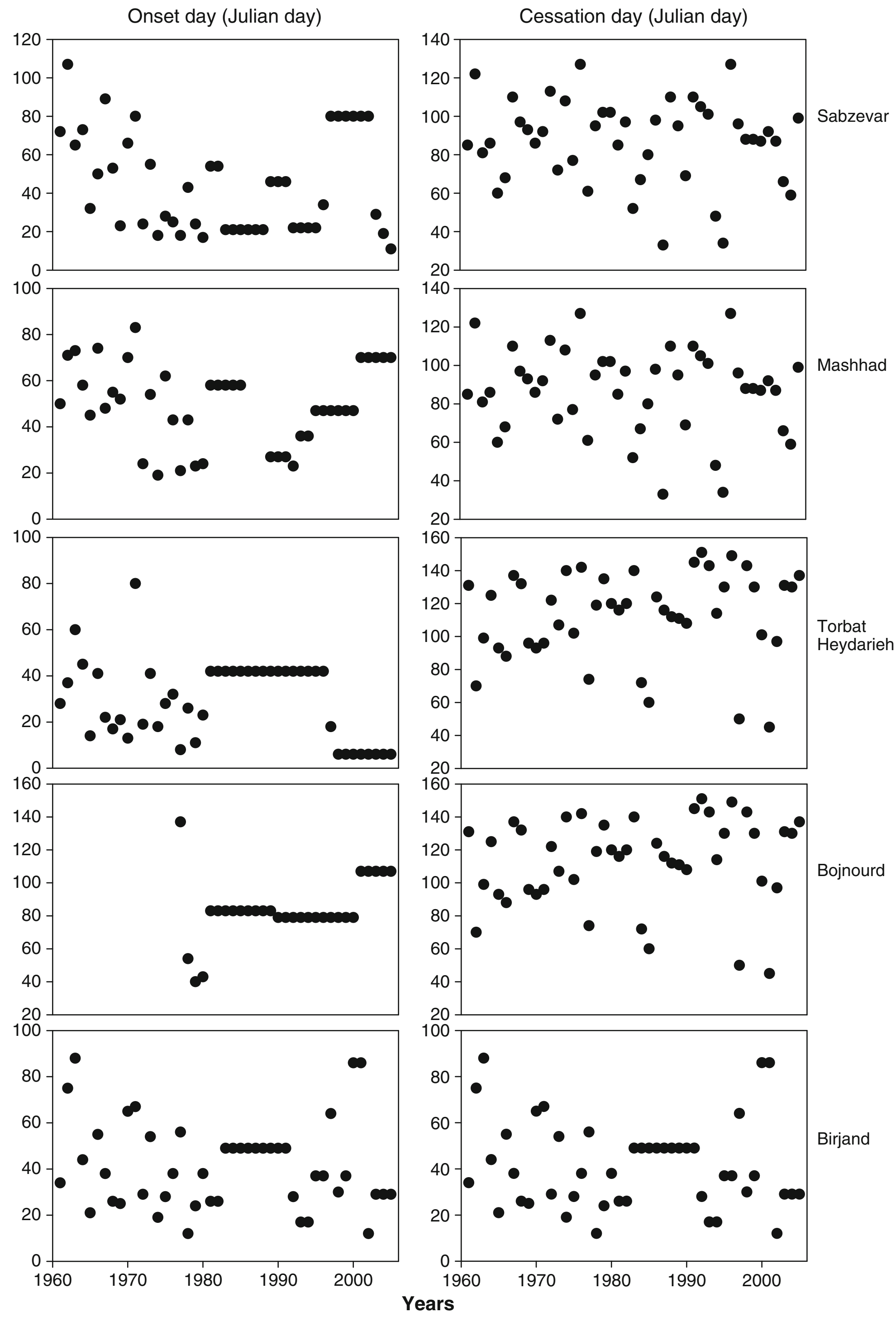
RAW were calculated as:

$$RAW = p^{*}TAW = 0.55^{*}TAW \tag{3}$$

It was assumed that, at the onset of the growing season, the soil water content is equal to RAW. ETc was estimated on a daily basis from Eq. 4. The effects of soil water stress, based on Allen et al. 1998 calculation algorithm, are described by multiplying the basal crop coefficient by the water stress coefficient, Ks. The effects of soil water stress on crop ET were accomplished by multiplying the crop coefficient by the water stress coefficient, Ks. Water content in the root zone can also be expressed by root zone depletion, Dr, i.e., water shortage relative to field capacity.

$$ETc = ETo^{*}Kc = ETo^{*}0.7 \tag{4}$$

Fig. 3 Scatter illustration of onset and cessation day of all study years and locations using temperature, precipitation, and evaporation for growing season indices calculation



Where

ETo = Potential evapotranspiration $\left(\mathrm{mm\,day}^{-1}\right)$

Following the actual evapotranspiration calculation, the index was calculated for 30-day period following the estimated onset date. As it was pointed out, if the index mean was less than 0.35, the calculated onset date was assumed as a false start. Complete details of calculation can be found in Allen et al. (1998).

3 Results and discussion

When the water is not the limiting factor, as expected, the longest growing season across all locations (forth quartile,

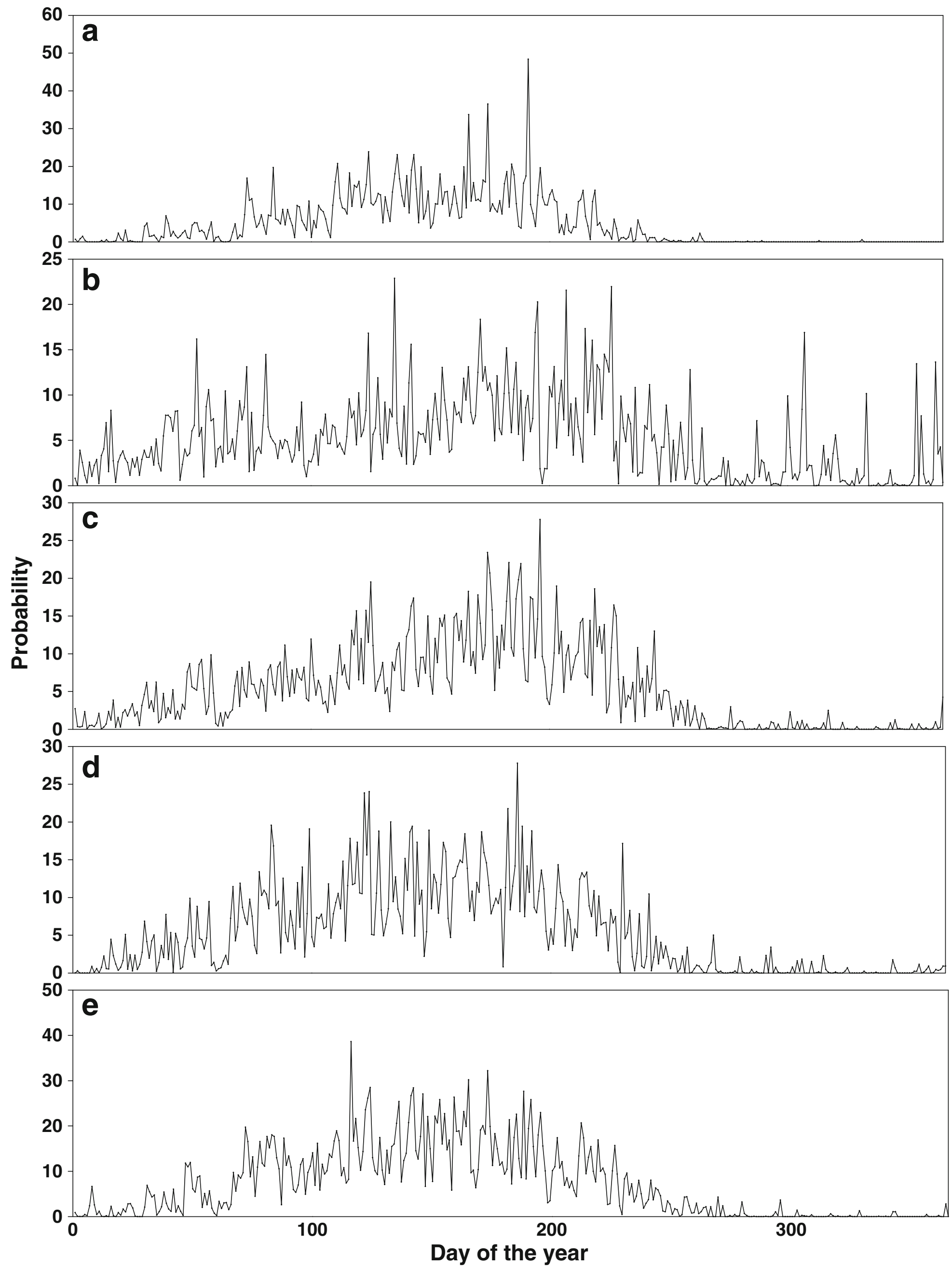


Fig. 4 Probability of availability of adequate water in 0.25 m of soil profile at each day of the year **a** Birjand, **b** Bojnourd, **c** Mashhad, **d** Sabzevar, and **e** Torbat heydarie. (The first day is 24th September)

Q4, Table 3) were, when the minimum temperature was 0°C and maximum temperature was 36°C (Table 3). Employing the temperature-only approach resulted in 197 days as the maximum length of the growing season which was obtained for Bojnourd, and the minimum length of the growing season was obtained as 154 days for Sabzevar. Table 3 shows that 75% of historical years indicated that, at minimum temperature of 0°C and maximum of 36°C, all study locations show about similar number of days as length of the growing season. However, as the minimum temperature increased, growing season for those types of crops which are not resistant to low temperatures and require higher minimum temperature, became shorter (Table 3). Our results indicated that, at potential level of production, Bojnourd and Torbat Heydarieh showed the highest potential for crop production. The results also showed that earliest onset of the growing season was when the minimum temperature was 0°C, and as the minimum temperature increased, the onset was later in the year for all locations. The earliest onset was in Bojnourd (Tmin=0°C, onset=first of January), and the latest onset of the growing season obtained for Mashhad (Tmin= 15°C, onset=24 July). It is obvious that the study locations are not suitable for tropical crops which require high base temperature. However, resistant crops to low temperature can benefit a long-growing season as long as there are no other limiting factors. As for cessation date, the latest cessation of the growing season was for Mashhad (26 July) and the earliest was for Sabzevar (9 April).

Considering the precipitation as the factor to determine the start of the growing season and temperature as the cessation of the growing season factor resulted in shorter growing season across all locations at all combination of temperatures (Table 4). Under such conditions, the maximum growing season length (124 days) was obtained for Sabzevar in 75% of historical years, as third quartile (Q3), and the shortest growing season (24 days) was at Birjand when minimum temperature was 15°C and maximum temperature was 32°C. Using this approach of calculation, in 75% of historical years the growing season length for those types of plants with at least 10°C as base temperature would be less than 2 months. In comparison between Bojnourd (north) and Birjand (south of the whole study region), with exception of 0–32°C, growing season length was always shorter in south. To achieve the benefits of such growing season with both temperatures as the cessation criteria and rainfall as the start of the growing season, the cropping system may require deficit irrigation during the growing season (De Costa and Shanmugathasan 2002). Using this approach, the earliest onset of the growing season was obtained at minimum temperature of 0°C for Sabzevar (Onset=8 January) and the latest onset belonged to Birjand (onset=29 December) which means only 1 day as the growing season. The earliest cessation date obtained for Birjand was the second of April when the maximum temperature was 32°C while the latest cessation obtained for all sites as the last day of the year (29th December) at all temperature ranges.

Table 4 Growing season length across all five locations based on temperature and rainfall approach

Region	Temperature range (°C)						
	0–32	0–36	5–32	5–36	10–32	10–36	15–36
	Q_0						
Bojnourd	14	5	0	0	0	0	0
Mashhad	10	17	3	11	0	0	0
Sabzevar	16	8	0	0	0	0	0
Torbat Heydarieh	2	30	0	0	0	0	0
Birjand	2	5	0	0	0	0	0
	Q_1						
Bojnourd	47	66	21	33	21	21	3.5
Mashhad	31	56	30	33	16	18	0
Sabzevar	43	59	21	30	16	13	13
Torbat Heydarieh	55	75	19	38	18	17	5
Birjand	38	67	13	15	0	0	0
	Q_2						
Bojnourd	65	86	33	51	33	42	27
Mashhad	62	74	52	47	30	30	24
Sabzevar	62	79	36	42	44	37	27
Torbat Heydarieh	76	95	40	56	30	30	20
Birjand	63	82	25	32	11	12	10
	Q_3						
Bojnourd	82	118	75.5	69	58	58	56
Mashhad	87	97	118	68	59	48	50
Sabzevar	87	104	124	59	84	51	42
Torbat Heydarieh	92	111	61	74	44	45	32
Birjand	88	98	56	53	31	31	24
	Q_4						
Bojnourd	263	178	262	208	199	178	175
Mashhad	265	159	260	219	258	219	123
Sabzevar	268	136	268	231	268	219	197
Torbat Heydarieh	263	299	262	229	244	90	90
Birjand	279	136	274	99	274	78	202

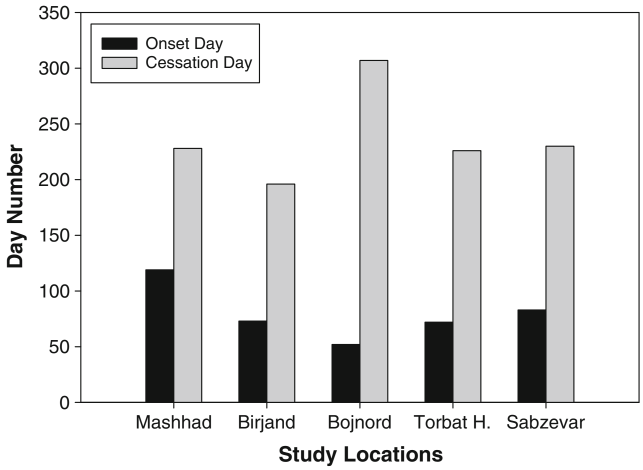


Fig. 5 Growing season characteristics across all five locations based on probability of 15% chance of availability of adequate water for a day (24th September were assumed as the first day of a year)

Employing the third approach which uses the water balance approach makes this approach similar to rainfed conditions showed that the longest growing season (147 days) was at Mashhad and the shortest (91 days) belonged to Bojnourd (Fig. 2). Third quartile values indicated that Sabzevar showed longer growing season length at 75% of historical years compared with other locations. In contrast to the second approach, Bojnourd which is located in the north of the study region showed shorter growing season length than Birjand which is located in the south of the region. Figure 3 shows the onset and cessation day for each year in each location. The highest variation in onset day was obtained for Birjand, and the most stable onset day was obtained for Bojnourd (Fig. 3). The earliest onset was obtained for Torbat Heydarieh (sixth of January) and the latest onset was for Bojnourd (17th May). In contrast to onset day, cessation day showed a high variation for all study locations (Fig. 3). Using this approach resulted in the earliest cessation of the growing season for Sabzevar (third February) and latest one for both Mashhad and Bojnourd (19th June).

The fourth approach (Fig. 4) indicated that the probability for any day with adequate soil moisture across all locations was always less than 50% across all historical years. It seems (Fig. 4) that Bojnourd has the longest growing season based on first day with 15% probability of available adequate water. The growing season length in Bojnourd is 255 days and begins 52 days after 24th September. Torbat Heydarieh, Sabzevar, Birjand, and Mashhad occupied the subsequent ranks, respectively (Fig. 5).

Comparison of false start percentage using rainfall and temperature approach indicated that, between different temperature thresholds, temperature of 15°C had lower percentage of false start across all locations except at Birjand. The third approach showed fewer false starts than second one for all locations. According to Table 5, in Mashhad, only 2.3% of the calculated onset dates using this approach were false start. Based on this approach, Birjand indicated the highest risk of cultivation due to high probability of false starts.

Employing the results of any approach depends on the farming system and value of the crop. The approaches which apply more factors for calculating the onset date usually resulted in fewer false starts but resulted in shorter growing season. It is speculated that the economic value and sensitivity of chosen crop to environment may affect the selection of the approach as well.

4 Conclusion

The results indicated that, when temperature is the only limiting factor, Bojnourd station showed the longest growing season, however, when precipitation was used along with temperature, longest growing season was obtained for Sabzevar station. The water balance model used, which simulates the rainfed conditions, showed the longest growing season for Mashhad station. Evaluation of false start of growing season indicated the lowest probability of false start occurrence for Mashhad compared with other locations. Analysis of onset and cessation results indicated that there is a tendency to start the growing season earlier and end it later from south to north of the

Table 5 Percentage of false start occurrence across all five locations using two different approaches

Region	Second approach				Third approach
	Minimum temperature, °C				
	0	5	10	15	
Mashhad	59%	85.7%	66.6%	26.6%	2.3%
Birjand	95.3%	100%	100%	100%	86.6%
Bojnord	63%	96%	59%	40.9%	51.7%
Torbate heydarieh	77.3%	97.5%	80%	48%	4.4%
Sabzevar	80%	94.9%	88.5%	76%	48.9%

The second approach used both temperature and rainfall information, and the third approach used temperature, rainfall, and evapotranspiration province. Employing the water balance approach showed that the longest growing season was at Mashhad, and the shortest belonged to Bojnourd. The high variation in rainfall from 1 year to another in all agro-ecological zones of Khorasan province indicates that practical advice to farmers based on calendar dates has no meaning. In addition, our results indicated that combining both water and temperature as limiting factors for calculating the onset date usually resulted in fewer false starts and in a shorter growing season. As the water is the main factor in rainfed system, water balance method is more promising for a more accurate cultivation plan.

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