Research Journal of Environmental Sciences

ISSN 1819-3412

Academic Journals Inc.

www.academicjournals.com

Research Journal of Environmental Sciences 3 (3): 299-310, 2009
ISSN 1819-3412

Past Runoff Trend for Declivitous Farms of Iran

M. Gholipoor
Department of Agronomy and Plant Breeding,
Shahrood University of Technology, P.O. Box 36155-316, Shahrood, Iran

Abstract: The regionally determination of direction of runoff changes is a challenging task. This simulation study was aimed to evaluate the past changes in runoff for sloped farms of five locations in Iran (Isfahan, Shiraz, Kermanshah, Tabriz and Mashhad) in 2006-2007. The soil water balance sub-model of CYRUS model with some modifications was used to calculate the value of runoff over monthly and yearly periods and over growing period of chickpea. The model was run for the daily weather data set from 1961 (or 1966) to 2004. Linear regression analyses were used to determine the trends (slopes) in value of runoff. The results indicated that in Isfahan, the value of runoff has increased for January, March and yearly period; on the other hand, it has had a downwardly change for April; runoff has shown statistically steady state for the rest months of the year. It appeared to have upwardly trend just for December in Shiraz. In Kermanshah, it was found the increasing trend in runoff for December, but decreasing trend for February and May. The months February and November have experienced the increasing risk of runoff in Tabriz and Mashhad, respectively. Over growing period of chickpea, this risk has been diminishing for Isfahan and Kermanshah; while it found to be constant for other locations. There is a consensus for inversed relation between recommendable slopes of land for planting the crops, including chickpea and risk of runoff; hence, it can be said that the recommendable slopes for planting the chickpea (*Cicer arietinum*) in declivitous farms of Isfahan and Kermanshah is steeper in 2000s as compared to those in 1960s.

Key words: Runoff, climate change, chickpea, CYRUS model, simulation

INTRODUCTION

There is a general consensus that global average surface air temperature has increased during the 20th century (Houghton *et al*., 2001). In most cases, the value of precipitation has changed dramatically. For example, Dai *et al*. (1997) found that on a globally averaged basis, precipitation over land has increased by about 2% over the years 1900-1997. Zonally averaged precipitation has increased by 7-12%, between 30 °N and 85 °N, compared with a 2% increase for 0-55 °S (Folland *et al*., 2001). Groisman *et al*. (2004) reported increases in precipitation over the conterminous USA during the 20th century, with most of the increase confined to the spring, summer and fall. Brown (2000) found systematic increases in winter (December through February) precipitation over North America averaging 3.9% per decade over the period 1915 through 1992. Mekis and Hogg (1999) showed that precipitation in Canada has increased by an average of more than 10% over the 20th century. Zhai *et al*. (1999a) reported the area affected by the upper 10% of heaviest precipitation has significantly increased. It has also been found an upwardly change in precipitation for many places, including west China (Zhai *et al*., 1999b), northern Europe (Schönwiese and Rapp, 1997), former USSR (Groisman and Rankova, 2001), Australia (Hennessy *et al*., 1999) and Southern Hemisphere (Dai *et al*., 1997).

On the other hand, some reports indicated the declining trend in precipitation during past decades. For example, an analysis of rainfall data since 1910 by Haylock and Nicholls (2000) reveals a large decrease in total precipitation and related rain days in southwestern Australia. Over the last 50 years, there has been a slight decrease in annual precipitation over China, which is supported by a significant (5% confidence level) decrease in the number of rainy days (3.9% per decade) (Zhai *et al*., 1999a). There have also been marked decreases in precipitation in some other regions, like southern Europe (Schönwiese and Rapp, 1997), Southeast Asia and the western and central South Pacific (Manton *et al*., 2001) and East Africa (Mwale *et al*., 2004).

It has been found by Georgievsky *et al*. (1996) the increases in precipitation over the last several decades over western Russia, accompanied by increases in stream flow (runoff) and a rise in the level of the Caspian Sea. Multidecadal stream flow data in Canada have revealed that there are no apparent inconsistencies between observed changes in stream flow and precipitation (Zhang *et al*., 2000). Published reports indicating that runoff from the Mississippi river increased by 22% from 1949 to 1997, during which time precipitation increased by 10% (Milly and Dunne, 2001). Several analyses (Groisman *et al*., 2001) have detected increases in stream flow across much of the contiguous United States, confirming the general tendency to increasing precipitation. Stream flow data for major rivers in southeastern South America for the period 1901 to 1995 show that stream flow has increased since the mid-1960s, which is in consistent with the changes in precipitation (Garcia and Vargas, 1998). Increases in precipitation over land have been associated with corresponding increases in runoff in river basins in the conterminous USA (Groisman *et al*., 2001). In Canada, increasing temperature combined with almost no change in precipitation, resulted in no change in annual stream flow from 1947 to 1996 for most regions (Zhang *et al*., 2001). In contrary with these findings, some reports indicating the inconsistencies between rainfall and runoff. As instance, Lins and Michaels (1994) found in some regions that changed stream flow did not relate well to an increase in rainfall; in Tien Shan Mountains in Northern Eurasia, precipitation has increased, snowfall decreased and runoff decreased or not changed during the latter half of the 20th century (Aizen *et al*., 1997). The reasons for inconsistencies between observed changes in stream flow and precipitation can be found in Huntington (2006).

The published reports regarding trends in runoff are rare for Iran. In one location of Iran, i.e., Gorgan, Gholipoor and Soltani (2005) has studied the changes in monthly value of runoff across years 1961-2001; in the procedure of calculation of runoff which they have used, the effect of some factors on runoff, including evaporation, snow-falling and snow-melting, has not been included. Therefore, the objective of this study was to evaluate the trends in runoff, using more efficient procedure; this evaluation was supposed to be in monthly and yearly point of view and in view point of growing period of chickpea for five locations of Iran. The result of this study may be useful for updating the recommendable value of slope for planting the crops, including chickpea, in declivitous farms.

MATERIALS AND METHODS

Model Description

A simulation study was conducted to determine the past changes in runoff for Iran in 2006-2007 at Shahrood University of Technology. In this study, the soil water balance sub-model of CYRUS model was used to calculate the daily value of runoff; firstly, it was recoded in Qbasic programming language and run for medium deep silty loam soil. This model was initially designed in 1999 by Soltani *et al*. (1999) for chickpea (*Cicer arietinum*). Then it was developed for seedling emergence (Soltani *et al*., 2006d), for leaf expansion and senescence (Soltani *et al*., 2006c), for response of leaf expansion and transpiration to soil water deficit (Soltani *et al*., 2000), for response to photoperiod (Soltani *et al*., 2004), for harvest index (Soltani *et al*., 2005), for phenological development (Soltani *et al*., 2006a), for nitrogen accumulation and partitioning (Soltani *et al*., 2006b) and for the effect of temperature and CO_2 (Soltani *et al*., 2007).

The CYRUS has been used for evaluating yield of chickpea and its stability in dormant seeding (Soltani and Torabi, 2007), determining optimum phenology of chickpea for now and future (Rahimi-Karizaki and Soltani, 2007), study of past climate change effects on chickpea phenology at different sowing dates (Gholipoor and Shahsavani, 2008), potential effects of individual versus simultaneous climate change factors on growth and water use in chickpea (Gholipoor, 2007), evaluating the effect of future climate change on yield of rainfed chickpea in northwest of Iran (Barzegar and Soltani, 2007), comparing relative effects of temperature and photoperiod on development rate of chickpea (Gholipoor and Soltani, 2006), optimizing the dormant sowing of chickpea (Gholipoor *et al*., 2006) and finding future climate impacts on chickpea in Iran and ICARDA (Gholipoor and Soltani, 2008). The soil water balance sub-model of this model with some modifications has been applied for comparative evaluating the climate-related runoff production in slopped farms of Iran (Gholipoor, 2008a).

Briefly, in soil water balance sub-model, daily soil water content is estimated as fraction transpirable soil water [FTSW, which ranges from 0 (point at which plants face with wilting) to 1 (field capacity)]. Similar to that described by Amir and Sinclair (1991), it accounted for additions from infiltration and losses from soil evaporation, transpiration and drainage. Infiltration is calculated from daily rainfall less any runoff. Runoff is estimated using the curve number technique (Knisel, 1980). Soil evaporation (E) is calculated using the two-stage model as implemented in spring wheat model developed by Amir and Sinclair (1991). Stage I E occurs when water present in the top 200 mm of soil and FTSW for the total profile is greater than 0.5. Stage II E occurs when the water in the top layer is exhausted or the FTSW for the total soil profile reaches to less than 0.5. In stage II, E is decreased substantially as a function of the square root of time since the start of stage II. The calculation of E is returned to stage I only when rain or irrigation of greater than 10 mm occurs. Like procedure of Tanner and Sinclair (1983) and Sinclair (1994), the daily transpiration rate is calculated directly from the daily rate of biomass production, transpiration efficiency coefficient (5 Pa) and VPD. The calculation of VPD is based on suggestion of Tanner and Sinclair (1983) that it to be approximately 0.75 of the difference between saturated vapor pressure calculated from daily maximum and minimum temperatures. Briefly description for other sub-models can be found by Gholipoor and Soltani (2008).

In this investigation, as mentioned previously, the sub-models regarding growth and development of chickpea were inactivated and only soil water balance sub-model was used; therefore, like previous work (Gholipoor, 2008a), some modifications were made as follows: (1) transpiration was assumed equal to zero, (2) a sub-model was added for calculating snow cover and snow melting as report of Ritchie (1991); this procedure has been used by many researchers including Soltani *et al*. (2006d); in this sub-model the value of snow is calculated based on maximum temperature; this temperature is also used for daily calculating amount of snow melting and (3) in original model, time course for calculations is growing period of chickpea; here it was also considered for monthly and yearly periods. It should be mentioned that the planting date for chickpea was considered as the 7 days with no rainfall and with mean temperature above the base temperature; then growing period was calculated on the basis of required growing degree days from planting to maturity.

Locations, Measured Attributes and Determining the Trends

Five locations with long-term and reliable daily weather data were selected for the study to represent a large geographical area and several climatic zones in Iran (Fig. 1 in Gholipoor (2008a)). The selected sites included Isfahan (32.67 °N, 51.87 °E and 1600 m asl), Shiraz (29.55 °N, 52.60 °E and 1488 m asl), Kermanshah (34.32 °N, 47.12 °E and 1322 m asl), Tabriz (38.13 °N, 46.28 °E and 1364 m asl) and Mashhad (36.27 °N, 59.63 °E and 990 m asl). Mean annual temperature is 16.4°C for Isfahan, 17.8°C for Shiraz, 14.4°C for Kermanshah, 12.6°C for Tabriz and 14.3°C for Mashhad. The annual rainfall occurs during 35 wet days for Isfahan, 42 for Shiraz, 74 for Kermanshah, 81 for Tabriz and 63 for Mashhad. For each location, 39 (1966-2004 for Tabriz) to 44 years (1961-2004) of daily data for rainfall and maximum and minimum temperatures and sunshine hours were available. Solar radiation data were calculated from sunshine hours and extraterrestrial solar radiation as outlined by Doorenbos and Pruitt (1977).

The calculated main attributes were runoff, number of days with runoff (R), frequency of R greater than zero and lower than and/or equal to 2 mm ($0<R\leq 2$), of $2<R\leq 4$, of $4<R\leq 6$ and of $6<R\leq 8$. Some other attributes were also calculated, including mean temperature, solar radiation, evaporation, probability of occurrence of rainfall (Ra), amount of Ra, number of days with Ra (wet days), frequency of $Ra\leq 5$ mm, of $5<Ra\leq 10$, of $10<Ra\leq 15$, of $15<Ra\leq 20$ and of $Ra>20$. Determination of probability of occurrence was achieved using generation of cumulative distribution functions (Purcell *et al*., 2003). Calculation of main attributes and of evaporation was done for sloped farms. The value of slope was considered to be 14%; because cultivation of crops is usually not recommendable in slops steeper than 14%.

If the changing trend of runoff, for example, to be increasing across first 20 years, but decreasing across last 24 years, it may be described by quadratic function; such changes may be considered as periodic-fluctuation, rather than consistent change, in runoff which is described by linear function. Therefore, as it has been done for temperature by Gholipoor (2008b) and for some climatic variables by Soltani and Soltani (2008), it was only used a simple linear regression function ($Y = a+bX$) to determine trends (slopes), i.e., b, in runoff and in other attributes; in this equation, Y is dependent variable (like runoff), X year, a intercept and b slope of regression line; the value of parameters (a and b) was calculated, using the procedure REG in SAS (1989). Like many researchers, including Soltani and Gholipoor (2006), the rates with probability level equal to and/or lower than 0.1 were considered as significant.

RESULTS AND DISCUSSION

The averaged values of runoff for slope 14% were presented in Fig. 1. In Isfahan, the monthly value of runoff was relatively considerable (1.03 to 2.29 mm) for months January to April; while it tended to be negligible (0.2 to 0.3 mm) for May, November and December; it was zero for the rest months of the year. Among locations, the highest monthly value of runoff (32 mm) was found for Shiraz (in January); in this location, amount of runoff declines to zero over May, June, August, September and October. In Kermanshah, that of runoff ranged from 10 to 15 mm over first four months of year and from 1.5 to 7.3 over May, October, November and December. Runoff tended to vary between 3.2 to 5.3 mm over March, April and May in Mashhad; it was little in firs two months of year and negligible in last two ones. In Tabriz, despite of above named locations, the average value of runoff does not decline to zero over summer and other months of the year; the probability of raining over July, August and September is 8.03% for this location, which is considerably higher than 0.54 to 2.83% for other locations; in Tabriz, like Kermanshah, the pick value of runoff is seen in March. The detailed cause of these mentioned variations between locations for value of runoff, including ratio of snow to rainfall, evaporation and occurrence of shallow, medium and heavy rainfalls, can be seen in report of Gholipoor (2008a).

The rate of change (value of b in equation $Y = a+bX$) and its probability level for 6 variables, including value of runoff (R), number of days with R, frequency of R greater than zero and lower than and/or equal to 2 mm ($0<R\leq 2$), of $2<R\leq 4$, of $4<R\leq 6$ and of $6<R\leq 8$ for Isfahan was shown in Table 1. In January, consistent with increased rainfall (Table 2), the past changes in value of runoff have been upwardly (2.64 mm per 44 years); frequency of $4<R\leq 6$ (almost heavy runoffs) found to be decreasing associated with corresponding downwardly trend for frequency of $Ra>20$ (Table 2); based on this change and on increasing trend of number of days with runoff, it can be cleared that incline in runoff has been due to enhancement in frequency, rather than intensity, of runoff. In February, the

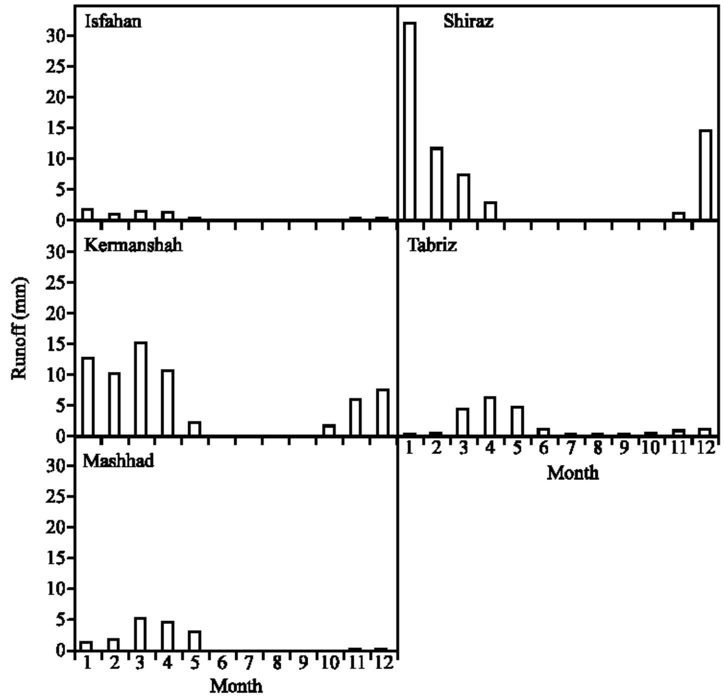

Fig. 1: The monthly sum value of runoff for slope 14% in five locations of Iran

Table 1: The rate of change and its probability level (P) for value of runoff (mm year^{-1}) and for number of days with runoff (R>0) (day year^{-1}), for frequency of runoff (R) greater than zero and lower than and/or equal to 2 mm ($0<R\leq 2$; day year^{-1}), of $2<R\leq 4$, of $4<R\leq 6$, of $6<R\leq 8$ across 1961-2004 in Isfahan, Iran

	Runoff		R>0		0<R<2		2<R<4		4<R<6		6<R<8	
Month	b	P	b	P	b	P	b	P	b	P	b	P
January	**0.068**	**0.05**	**0.032**	**0.04**	0.011	0.27	0.001	0.69	**-0.007**	**0.04**	-----	-----
February	0.015	0.78	-0.017	0.22	**-0.022**	**0.05**	0.001	0.71	0.004	0.14	-----	-----
March	**0.060**	**0.10**	0.022	0.17	0.013	0.33	0.000	0.90	0.006	0.17	0.002	0.20
April	**-0.069**	**0.05**	**-0.029**	**0.08**	-0.018	0.19	-0.003	0.38	-0.001	0.61	**-0.006**	**0.10**
May	0.006	0.51	-0.004	0.63	-0.004	0.54	-0.001	0.61	0.002	0.33	-----	-----
June	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
July	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
August	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
September	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
October	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
November	0.005	0.42	0.001	0.58	0.000	0.97	-----	-----	-----	-----	-----	-----
December	0.005	0.77	0.002	0.78	0.001	0.72	-----	-----	-----	-----	-----	-----
#Chickpea	**-0.069**	**0.08**	**-0.038**	**0.08**	-0.020	0.44	-0.003	0.76	0.002	0.91	-0.004	0.44
Year	**0.090**	**0.08**	0.007	0.97	-0.019	0.44	-0.001	0.98	0.004	0.44	-0.004	0.73

#: Growing period of chickpea (day of year 58-176). The bold values are significant

changes in rainfall and consequently in runoff were not sensible; just it was found statistically significant decrease in frequency of $0<R\leq 2$. The ratio regarding rate of increase in rainfall to that of incline in runoff tended to be 8.33 in March, which is considerably higher than that in January (4.76); in other words, the rate of increase in precipitation was higher in March as compared to that in January; while, that of incline in runoff was unexpectedly lower in March, when compared with that in January; part of this can be attributed to evaporation which its upwardly trend appeared to be

Table 2: The rate of change and its probability level (P) for value of evaporation (mm $year^{-1}$) and of rainfall (mm $year^{-1}$), for number of days with rainfall (wet days; day $year^{-1}$) and with heavy rainfalls (rainfall>20 mm; day $year^{-1}$), for mean temperature (°C $year^{-1}$) and for solar radiation (MJ/m^2/day/year) across 1961-2004 in Isfahan, Iran

	Rainfall		Wet days		Rainfall>20 mm		Evaporation		Mean temperature		Solar radiation	
Month	b	P	b	P	b	P	b	P	b	P	b	P
January	**0.324**	**0.09**	0.023	0.51	**-0.013**	**0.03**	0.151	0.17	0.016	0.54	0.007	0.57
February	0.054	0.75	0.019	0.51	0.001	0.66	0.154	0.25	0.013	0.57	**0.051**	**0.00**
March	**0.530**	**0.01**	0.054	0.14	0.002	0.23	**0.370**	**0.05**	-0.026	0.20	**0.030**	**0.03**
April	-0.138	0.49	-0.026	0.54	-----	-----	0.196	0.39	**0.042**	**0.01**	0.012	0.42
May	-0.049	0.74	-0.036	0.27	-----	-----	-0.008	0.96	0.015	0.33	-0.019	0.22
June	**0.063**	**0.04**	0.011	0.31	-----	-----	-0.068	0.58	0.012	0.25	-0.008	0.43
July	0.013	0.49	0.011	0.33	-----	-----	0.004	0.91	0.012	0.34	**-0.047**	**0.00**
August	0.003	0.72	0.007	0.41	-----	-----	0.031	0.13	**0.028**	**0.04**	-0.008	0.36
September	-0.002	0.32	0.003	0.52	-----	-----	**0.029**	**0.04**	**0.036**	**0.00**	0.015	0.11
October	-0.047	0.58	0.015	0.52	-----	-----	-0.029	0.59	**0.025**	**0.08**	**0.030**	**0.01**
November	0.054	0.69	0.015	0.58	0.001	0.41	-0.081	0.47	**0.025**	**0.08**	-0.013	0.20
December	0.133	0.48	0.050	0.18	0.000	0.91	0.033	0.79	0.031	0.13	-0.012	0.16
#Chickpea	0.381	0.26	-0.004	0.95	0.002	0.72	**0.502**	**0.09**	0.011	0.28	0.005	0.50
Year	**0.938**	**0.05**	0.146	0.22	-0.009	0.11	0.782	0.14	**0.229**	**0.01**	0.038	0.39

#: Growing period of chickpea (day of year 58-176). The bold values are significant

statistically considerable in March, but negligible in January (Table 2); it should be mentioned that the change in evaporation for March has been due to increase in solar radiation, not to that in temperature (Table 2). In April, little (statistically negligible) diminishing trend in precipitation and on the other hand, little (negligible) increasing trend in evaporation have caused that decline in runoff to be huge (3.04 mm per 44 years); this decrease has been accompanied by decline in frequency of $6<R\leq 8$ (0.26 day per 44 years) and in number of days with runoff (1.28 days per 44 years). As mentioned previously, over June, July, August, September and October, the rare rainfall (the probability of occurring is about 2%) tends to infiltrate completely, even into the soil of declivitous (14%) lands. The value of runoff has statistically been constant for November and December; these months have never experienced runoff greater than 2 and lower than and/or equal to 8 mm. Due to increased evaporation by 0.502 mm $year^{-1}$, runoff has been decreasing for growing period of chickpea. In yearly point of view, the value of runoff has changed from 5.29 mm in 1961 to 9.25 mm in 2004 (about 0.09 mm $year^{-1}$), which is in agreement with reports for other countries (e.g., Groisman *et al*., 2001; Zhang *et al*., 2000).

In Shiraz, the probable stimulating effect of increased frequency of $0<Ra\leq 5$ (data for frequency of different values of rainfall, for wet days, evaporation, rainfall, mean temperature and solar radiation not shown for Shiraz and for other locations which are discussed latter) on runoff might be counterbalanced by enhanced evaporation for January; therefore, the value of runoff in this month, which is the highest, has fortunately not increased (Table 3). In February, there have been no change in rainfall and hence in runoff; this was true for evaporation, but not for solar radiation and mean temperature; they have had directed change with incrementing the year. In March, the increase in frequency of $10<Ra\leq 15$ has been accompanied by incline in that of $0<R\leq 2$ during 1961 to 2004; despite of this change, amount of runoff has been the same; this was also true for evaporation. In April, just frequency of $6<R<8$ has been diminishing. No changes in rainfall and evaporation have been associated with corresponding constancy in runoff for November. Positively correlated with precipitation (0.606 mm $year^{-1}$) and frequency of $Ra>20$ (about one day per 44 years), it found about 9.06 mm per 44 years increase in runoff for December; the intensity of runoff has been changed as enhanced frequency of $4<R<6$ by about 0.79 day per 44 years; the value of temperature and solar radiation and consequently that of evaporation has been the same across tested years; therefore, it can be said that the increase in runoff has not been alleviated by evaporation-related losses of soil water. The statistically negligible and/or considerable increased frequency of $4<R\leq 6$ in January, February,

Table 3: The rate of change and its probability level (P) for value of runoff (mm $year^{-1}$) and for number of days with runoff (R>0) (day $year^{-1}$), for frequency of runoff (R) greater than zero and lower than and/or equal to 2 mm ($0<R\le 2$; day $year^{-1}$), of $2<R\le 4$, of $4<R\le 6$, of $6<R\le 8$ across 1961-2004 in Shiraz, Iran

	Runoff		R>0		$0<R\le 2$		$2<R\le 4$		$4<R\le 6$		$6<R\le 8$	
Month	b	P	b	P	b	P	b	P	b	P	b	P
January	0.473	0.31	0.010	0.80	-0.009	0.67	-0.009	0.40	0.002	0.84	0.001	0.74
February	0.054	0.79	0.007	0.79	0.005	0.77	-0.005	0.46	0.003	0.37	-0.003	0.35
March	0.090	0.56	0.036	0.25	**0.039**	**0.09**	0.000	0.96	-0.009	0.21	0.001	0.73
April	-0.195	0.14	-0.028	0.14	-0.011	0.34	-0.003	0.29	-0.001	0.56	**-0.008**	**0.01**
May	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
June	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
July	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
August	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
September	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
October	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
November	-0.066	0.35	0.002	0.81	0.001	0.85	0.002	0.37	0.002	0.37	-----	-----
December	**0.206**	**0.05**	**0.068**	**0.03**	0.020	0.28	0.003	0.70	**0.018**	**0.01**	0.001	0.75
#Chickpea	-0.115	0.43	0.005	0.66	0.029	0.34	-0.004	0.39	-0.009	0.46	**-0.008**	**0.04**
Year	0.562	0.18	0.095	0.10	0.045	0.27	-0.013	0.47	0.016	0.28	-0.007	0.32

#: Growing period of chickpea (day of year 54-172). The bold values are significant

Table 4: The rate of change and its probability level (P) for value of runoff (mm $year^{-1}$) and for number of days with runoff (R>0) (day $year^{-1}$), for frequency of runoff (R) greater than zero and lower than and/or equal to 2 mm ($0<R\le 2$; day $year^{-1}$), of $2<R\le 4$, of $4<R\le 6$, of $6<R\le 8$ across 1961-2004 in Kermanshah, Iran

	Runoff		R>0		$0<R\le 2$		$2<R\le 4$		$4<R\le 6$		$6<R\le 8$	
Month	b	P	b	P	b	P	b	P	b	P	b	P
January	-0.037	0.75	-0.008	0.79	-0.006	0.80	-0.008	0.36	-0.017	0.11	-0.007	0.12
February	**-0.216**	**0.03**	-0.005	0.88	0.001	0.98	0.000	0.99	-0.003	0.69	-0.003	0.35
March	-0.023	0.93	-0.012	0.77	-0.022	0.38	0.007	0.38	0.010	0.20	0.001	0.96
April	-0.239	0.14	**-0.073**	**0.02**	**-0.044**	**0.01**	**-0.016**	**0.08**	-0.004	0.60	0.001	0.95
May	**-0.322**	**0.03**	**-0.052**	**0.04**	**-0.035**	**0.06**	**-0.008**	**0.05**	**-0.005**	**0.10**	-----	-----
June	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
July	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
August	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
September	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
October	-0.088	0.26	-0.004	0.72	0.000	0.95	-0.002	0.17	0.002	0.37	0.001	0.73
November	0.178	0.51	-0.006	0.80	-0.007	0.68	-0.005	0.34	0.003	0.37	-0.009	0.12
December	**0.200**	**0.10**	0.040	0.19	0.015	0.39	0.005	0.65	**0.016**	**0.10**	0.000	0.87
#Chickpea	**-0.631**	**0.04**	**-0.133**	**0.04**	**-0.087**	**0.04**	**-0.021**	**0.08**	-0.009	0.88	0.001	0.98
Year	-0.547	0.35	-0.120	0.14	**-0.098**	**0.10**	-0.026	0.17	0.002	0.97	**-0.016**	**0.09**

#: Growing period of chickpea (day of year 83-201). The bold values are significant

November and December might be counterbalanced by statistically negligible decreased that of $4<R\le 6$ in March and April; as a result, in yearly point of view, the rate of change in this attribute was statistically zero; nearly similar pattern was also true for other attributes, including frequency of $0<R\le 2$. The no change in annual runoff has also been found for Canada (Zhang *et al*., 2001). In growing period of chickpea, it found a decreased frequency of $6<R\le 8$ associated with downwardly change in that of Ra>20.

The rate of changes in measured attributes regarding runoff for Kermanshah was presented in Table 4. The value of b for runoff and other attributes was statistically zero in January and March. That of runoff, which is relatively considerable (averagely 9.96 mm) in February, has fortunately diminished; this has just been due to the optimized distribution of rainfall (decreased frequency of Ra>20 by 0.06 day $year^{-1}$, with no change in value of rainfall). In April, the considerable decrease in rainfall has been accompanied by remarkable decline in frequency of $0<R\le 4$; despite of this change, amount of runoff has statistically been remained constant. The month May tended to be characterized as the month with no happening of $6<R\le 8$; the changes in runoff and frequency of $0<R\le 6$ have been diminishing for this month; part of the reasons for these changes may be due to diminished value of

rainfall (0.71 mm year^{-1}); warming the temperature (about 0.03°C year^{-1}) and consequently intensified evaporation (0.42 mm year^{-1}) has also been cause of the named changes. In October and November, despite of warming the temperature by 0.06 and 0.04°C year^{-1}, respectively, the value of evaporation, rainfall and hence, that of runoff appeared to show constancy. The month December was characterized by worsening of rain distribution, i.e., increased frequency of Ra>20, with no change in value of rainfall; this situation has caused that the frequency of $4<R\leq 6$ and as a result, the value of runoff to have directed change with incrementing the years from 1961 to 2004. The downwardly change in frequency of $0<R\leq 4$ and in amount of runoff found to be significant for growing period of chickpea, due to diminished rainfall. The results regarding yearly calculations indicated that among attributes presented in Table 4, the decreasing trend has statistically been true just for frequency of $0<R<2$ and $6<R\leq 8$.

The value of b for measured attributes regarding Tabriz was shown in Table 5. For January, the decrease in value of rainfall by about 0.31 mm year^{-1} with no change in frequency of Ra>20, have resulted in that frequency of $4<R\leq 6$ to show downwardly trend; despite of this lessened frequency of almost heavy runoffs, amount of runoff has been the same across years 1966 to 2004; that of evaporation found to be not affected by significant warming and intensified reaching of solar radiation to soil surface (0.05 MJ/m^2/day/ year) during named years. As compared to January, the rising slope of mean temperature and solar radiation has been more considerable in February; therefore the increase in evaporation found to be considerable (0.54 mm year^{-1}) in this month, but as mentioned, negligible in January; declined rainfall and such change in evaporation for February have caused that the risk of runoff to be alleviated (i.e., decreased runoff). In March, June, August, September, November, December and yearly period, the value of b was statistically zero for value of runoff and for frequency of different values of runoff; in most cases, this might be due to no change in rainfall (September and yearly period with declined rainfall were exceptions). Because of significant changes in rainfall intensity, the frequency of $4<R\leq 6$, of $2<R\leq 4$ and of $0<R\leq 2$ have being rising for months April, May and July, respectively; the amount of runoff has been the same for named months, due to no change in amount of rainfall. In growing period of chickpea, it was found a steady state for value of runoff and for frequency of calculated values of runoff.

As it was presented for Mashhad in Table 6, the value of runoff has had a plateau state across the years 1961 to 2004 for January; this has been associated with corresponding plateau state for

Table 5: The rate of change and its probability level (P) for value of runoff (mm year^{-1}) and for number of days with runoff (R>0) (day year^{-1}), for frequency of runoff (R) greater than zero and lower than and/or equal to 2 mm ($0<R\leq 2$; day year^{-1}), of $2<R\leq 4$, of $4<R\leq 6$, of $6<R\leq 8$ across 1966-2004 in Tabriz, Iran

	Runoff		R>0		$0<R\leq 2$		$2<R\leq 4$		$4<R\leq 6$		$6<R<8$	
Month	b	P	b	P	b	P	b	P	b	P	b	P
January	-0.009	0.18	0.003	0.84	0.004	0.80	0.004	0.16	**-0.006**	**0.09**	-----	-----
February	**-0.037**	**0.08**	-0.014	0.36	**-0.029**	**0.07**	0.001	0.88	-0.002	0.29	-----	-----
March	-0.029	0.18	-0.027	0.40	-0.020	0.48	-0.006	0.49	0.003	0.52	0.002	0.48
April	0.070	0.60	0.032	0.30	-0.017	0.59	-0.005	0.61	**0.012**	**0.05**	-0.001	0.88
May	-0.032	0.71	0.010	0.76	-0.011	0.68	**0.013**	**0.10**	-0.002	0.71	0.002	0.76
June	-0.028	0.56	0.002	0.90	0.004	0.77	-0.001	0.82	-----	-----	-----	-----
July	0.007	0.37	**0.013**	**0.10**	**0.012**	**0.09**	-0.001	0.60	-----	-----	-----	-----
August	0.007	0.49	0.003	0.31	0.003	0.25	0.001	0.79	-----	-----	-----	-----
September	0.002	0.81	0.002	0.64	0.001	0.76	0.000	0.86	-----	-----	-----	-----
October	0.014	0.73	-0.002	0.88	-0.004	0.65	0.002	0.73	-----	-----	-----	-----
November	0.022	0.53	0.010	0.62	0.007	0.70	0.004	0.62	0.003	0.16	-----	-----
December	0.012	0.80	-0.021	0.39	-0.019	0.34	-0.002	0.57	0.001	0.86	-----	-----
#Chickpea	0.019	0.94	0.050	0.11	-0.010	0.30	0.007	0.80	0.011	0.19	0.001	0.91
Year	-0.001	0.65	0.011	0.90	-0.070	0.44	0.010	0.49	0.009	0.34	0.003	0.69

#: Growing period of chickpea (day of year 95-207). The bold values are significant

Table 6: The rate of change and its probability level (P) for value of runoff (mm year^{-1}) and for number of days with runoff (R>0) (day year^{-1}), for frequency of runoff (R) greater than zero and lower than and/or equal to 2 mm ($0<R\leq 2$; day year^{-1}), of $2<R\leq 4$, of $4<R\leq 6$, of $6<R\leq 8$ across 1961-2004 in Mashhad, Iran

	Runoff		R>0		$0<R\leq 2$		$2<R\leq 4$		$4<R\leq 6$		$6<R\leq 8$	
Month	b	P	b	P	b	P	b	P	b	P	b	P
January	0.024	0.56	**0.037**	**0.02**	**0.041**	**0.02**	**0.008**	**0.06**	**-0.009**	**0.08**	-----	-----
February	0.005	0.92	-0.010	0.47	-0.003	0.87	-0.003	0.61	0.002	0.60	-----	-----
March	-0.032	0.67	0.001	0.96	-0.008	0.73	0.001	0.89	0.004	0.55	-0.005	0.17
April	-0.080	0.36	**-0.061**	**0.00**	**-0.049**	**0.00**	**-0.005**	**0.43**	**-0.007**	**0.06**	**0.008**	**0.04**
May	-0.001	0.99	-0.001	0.97	-0.012	0.49	**0.009**	**0.10**	**-0.006**	**0.08**	-0.001	0.41
June	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
July	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
August	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
September	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
October	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
November	**-0.046**	**0.09**	-0.004	0.44	0.001	0.58	-0.001	0.56	-----	-----	-----	-----
December	-0.012	0.50	0.008	0.34	0.006	0.43	0.000	0.85	-----	-----	-----	-----
#Chickpea	-0.098	0.49	**-0.063**	**0.04**	**-0.066**	**0.03**	0.004	0.66	**-0.011**	**0.06**	0.003	0.29
Year	-0.142	0.36	-0.029	0.55	-0.024	0.64	0.009	0.57	-0.016	0.35	0.002	0.23

#: Growing period of chickpea (day of year 71-189). The bold values are significant

rainfall and evaporation; on the other hand, the intensity of runoff has been changed as decrease in frequency of $4<R\leq 6$, but rise in that of $0<R\leq 4$; this has been accompanied by decrease in frequency of Ra>20. The increase in solar radiation and consequently intensified evaporation appeared to be significant for February and March; despite of these changes, the amount of rainfall and hence that of runoff have remained constant; positively correlated with frequency of different values of rainfall, it found a constancy in frequency of different values of runoff. In April, the intensity of runoff has been changed as amplified frequency of $6<R\leq 8$ and on the other hand, as deducted that of $0<R\leq 2$ and $4<R\leq 6$; this has been related to decreased evaporation and to increased frequency of $15<Ra\leq 20$; in contrary with these changes, the value of runoff has been constant. Corresponded with trivialized frequency of $15<Ra\leq 20$, that of $4<R\leq 6$ has been abated for May; on the other hand, happening of $2<R\leq 4$ has been intensified. In November, the decreased amount of runoff may be attributable only to warming-resulted rises in loss of soil water through evaporation (0.19 mm year^{-1}); such exclusive attributing is due to no changes in value and intensity of rainfall; the decreasing trend in runoff for this month is consistent with report of Aizen *et al*. (1997) for some regions of Tien Shan Mountains in Northern Eurasia. For December and yearly period, the value of b was statistically zero for all presented attributes in Table 6. In view point of chickpea growing period, frequency of $0<R\leq 2$ and $4<R\leq 6$ has been diminishing.

CONCLUSION

The results indicated that in Isfahan, the value of runoff has increased for January, March and yearly period; on the other hand, it has had a downwardly change for April; runoff has shown statistically steady state for the rest months of the year. It appeared to have upwardly trend just for December in Shiraz. In Kermanshah, it was found the increasing trend in runoff for December, but decreasing trend for February and May. The months February and November have experienced the increasing risk of runoff in Tabriz and Mashhad, respectively. Over growing period of chickpea, this risk has been diminishing for Isfahan and Kermanshah; while it found to be constant for other locations.

Plowing the soil in declivitous farms for planting the crops makes the soil more susceptible to runoff-resulted erosion. Therefore, the recommendable value of slope of land is determined using the value (risk) of runoff. Accordingly it can be concluded that the recommendable slopes for planting the chickpea in declivitous farms of Isfahan and Kermanshah is steeper in 2000s as compared to 1960s.

Similar conclusion can be derived for other crops with different season of growth and development. In agronomy point of view, such changes may be useful to extend the planting area. While in more cases, the decrease in runoff is coincided with diminished rainfall; in such conditions, the strategies for decreasing the loss of soil water may be more important. Leaving the crop residue on soil surface could decreased evaporation; some other benefits can be defined as increase the soil infiltration and consequently decreased runoff, enhancing yield (Power *et al*., 1998), soil organic carbon (Clapp *et al*., 2000), soil nitrogen content (Kumar and Goh, 2000) and C/N ratio (Martens, 2000).

REFERENCES

Aizen, V.B., E.M. Aizen, J.M. Melack and J. Dozier, 1997. Climatic and hydrologic changes in the Tien Shan, Central Asia. J. Climate, 10: 1393-1404.

Amir, J. and T.R. Sinclair, 1991. A model of water limitation on spring wheat growth and yield. Field Crops Res., 29: 59-69.

Barzegar, A.B. and A. Soltani, 2007. Effect of future climate change on yield of rainfed chickpea in northwest of Iran (Text in Persian, abstract in English). Proceedings of 2nd National Symposium of Organic Farming, Oct. 16-17, University of Agricultural Sciences and Natural Resources, Gorgan, Iran, pp: 569-587.

Brown, R.D., 2000. Northern hemisphere snow cover variability and change. J. Climate, 13: 2339-2355.

Clapp, C.E., R.R. Allmaras, M.F. Layese, D.R. Linden and R.H. Dowdy, 2000. Soil organic carbon and 13-C abundance as related to tillage, crop residue, and nitrogen fertilizer under continuous corn management in Minnesota. Soil Tillage Res., 55: 127-142.

Dai, A., I.Y. Fung and A.D. DelGenio, 1997. Surface observed global land precipitation variations during 1900-1988. J. Climate, 10: 2943-2962.

Doorenbos, J. and W.O. Pruitt, 1977. Guidelines for Predicting Crop Water Requirements. (FAO Irrigation and Drainage Paper 24). 2nd Edn. FAO, Rome, Italy, ISBN: 92-5-200136-0, pp: 179.

Folland, C.K., T.R. Karl, J.R. Christy, R.A. Clarke and G.V. Gruza *et al*., 2001. Observed Climate Variability and Change. In: Climate Change 2001: The Scientific Basis, Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer and P.J. Van der Linder *et al*. (Eds.). Cambridge University Press, Cambridge, pp: 99-181.

Garcia, N.O. and W.M. Vargas, 1998. The temporal climatic variability in the Rio de la Plata basin displayed by the river discharges. Climate Change, 38: 359-379.

Georgievsky, V., A. Yu, A.V. Ezhov, I.A. Shalygin and I.A. Shiklomanov *et al*., 1996. Assessment of the effect of possible climate changes on hydrologic regime and water resources of rivers in the former USSR. Russian Meteorol. Hydrol., 11: 66-74.

Gholipoor, M. and A. Soltani, 2005. Effect of past climate change on runoff in Gorgan. (Text in Persian). Proceedings of 5th Iranian Hydrolic Conference, Nov. 8-10, Shahid Bahonar University of Kerman, Kerman, Iran, pp: 1685-1692.

Gholipoor, M. and A. Soltani, 2006. Comparing relative effects of temperature and photoperiod on development rate of chickpea, using simulation. Proceedings of 9th Iranian Crop Science Congress, August 27-29, Aboureyhan Campus-University of Tehran, Tehran, Iran, pp: 440-440.

Gholipoor, M., A. Soltani and S. Sharafi, 2006. Determining optimum sowing date for dormant seeding of chickpea in Kermanshah using simulation. Proceedings of 9th Iranian Crop Science Congress, August 27-29, Aboureyhan Campus-University of Tehran, Iran, pp: 159-159 (In Persian).

Gholipoor, M., 2007. Potential effects of individual versus simultaneous climate change factors on growth and water use in chickpea. Int. J. Plant Prod., 1: 189-204.

Gholipoor, M., 2008a. Comparative evaluating the climate-related runoff production in slopped farms of Iran, using simulation. Asian J. Agric. Res., 2: 45-55.

Gholipoor, M., 2008b. Evaluating past surface air temperature change in Tabriz, Iran using hourly-based analyzing. Int. J. Agric. Res., 3: 131-139.

Gholipoor, M. and A. Soltani, 2008. Future climate impacts on chickpea in Iran and ICARDA. Res. J. Environ. Sci. (In Press).

Gholipoor, M. and S. Shahsavani, 2008. Simulation study of past climate change effect on chickpea phenology at different sowing dates in Gorgan, Iran. Pak. J. Biol. Sci., 11: 1561-1568.

Groisman, P.Y. and E.Y. Rankova, 2001. Precipitation trends over the Russian permafrost-free zone: Removing the artifacts of pre-processing. Int. J. Climatol., 21: 657-678.

Groisman, P.Y., P.W. Knight and T.R. Karl, 2001. Heavy precipitation and high stream flow in the United States: Trends in the 20th Century. Bull. Am. Meteorol. Soc., 82: 219-246.

Groisman, P.Y., R.W. Knight, T.R. Karl, D.R. Easterling, B. Sun and J. Lawrimore, 2004. Contemporary changes of the hydrological cycle over the contiguous United States: Trends. J. Hydrometeorol., 5: 64-85.

Haylock, M. and M. Nicholls, 2000. Trends in extreme rainfall indices for an updated high quality data set for Australia, 1910-1998. Int. J. Climatol., 20: 1533-1541.

Hennessy, K.J., R. Suppiah and C.M. Page, 1999. Australian rainfall changes, 1910-1995. Aust. Meteorol. Mag. 48: 1-13.

Houghton, J.T., Y. Ding, D.C. Griggs, M. Noguer and P.J. van der Linden *et al*., 2001. Climate Change 2001: The Scientific Basis Contribution of Working Group I to the 3rd Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK., ISBN-10: 0521014956.

Huntington, T.G., 2006. Evidence for intensification of the global water cycle: Review and synthesis. J. Hydrol., 319: 83-95.

Knisel, W.G., 1980. CREAMS: A filed-scale model for chemicals, runoff and erosion from agricultural management systems. Conservation Research Report 26, USDA, US. Gov. Print. Office, Washington DC.,

Kumar, K. and K.M. Goh, 2000. Crop residues and management practices: Effects on soil quality, soil nitrogen dynamics, crop yield and nitrogen recovery. Adv. Agron., 68: 197-319.

Lins, H.F. and P.J. Michaels, 1994. Increasing US streamflow linked to greenhouse forcing. EOS, Trans. AGU., 75: 284-285.

Manton, M.J., P.M. Della-Marta, M.R. Haylock, K.J. Hennessy, N. Nicholls and L.E. Chambers, 2001. Trends in extreme daily rainfall and temperature in Southeast Asia and the South Pacific: 1961-1998. Int. J. Climatol., 21: 269-284.

Martens, D.A., 2000. Plant residue biochemistry regulates soil carbon cycling and carbon sequestration. Soil Biol. Biochem., 32: 361-369.

Mekis, E. and W.D. Hogg, 1999. Rehabilitation and analysis of Canadian daily precipitation time series. Atmos. Ocean, 37: 53-85.

Milly, P.C.D. and K.A. Dunne, 2001. Trends in evaporation and surface cooling in the Mississippi River basin. Geophys. Res. Lett., 28: 1219-1222.

Mwale, D., T.Y. Gan and S.S.P. Shen, 2004. A new analysis on variability and predictability of seasonal rainfall of central Southern Africa. Int. J. Climatol., 24: 1509-1530.

Power, J.F., P.T. Koerner, J.W. Doran and W.W. Wilhelm, 1998. Residual effects of crop residues on grain production and selected soil properties. Soil Sci. Soc. Am. J., 62: 1393-1397.

Purcell, I.C., T.R. Sinclair and R.W. McNew, 2003. Drought avoidance assessment for summer annual crops using long-term weather data. Agron. J., 95: 1566-1576.

Rahimi-Karizaki, A. and A. Soltani, 2007. Determining optimum phenology of chickpea for now and future. Proceedings of 2nd National Symposium of Organic Farming, Oct. 16-17, University of Agricultural Sciences and Natural Resources, Gorgan, Iran, pp: 603-620.

Ritchie, J.T., 1991. Wheat Pasic Development. In: Modeling Plant and Soil Systems, Hanks, R.J. and J.T. Ritchie (Eds.). Agronomy Monograph, No. 31, pp: 31-54.

SAS, 1989. SAS/STAT Users Guide. Version 6, 4th Edn., SAS Institute, Cary, NC.

Schönwiese, C.D. and J. Rapp, 1997. Climate Trend Atlas of Europe Based on Observations, 1891-1990. 1st Edn., Springer, Dordrecht, Netherlands, pp: 240.

Sinclair, T.R., 1994. Limits to Crop Yield. In: Physiology and Determination of Crop Yield. Boote, K.J., J.M. Bennet, T.R. Sinclair and G.N. Paulsen (Eds.). ASA, CSSA and SSSA, Madison, WI, ISBN-10: 0891181229, pp: 509-532.

Soltani, A., K. Ghassemi-Golezani, F.R. Khooie and M. Moghaddam, 1999. A simple model for chickpea growth and yield. Field Crops Res., 62: 213-224.

Soltani, A., F.R. Khooie, K. Ghassemi-Golezani and M. Moghaddam, 2000. Thresholds for chickpea leaf expansion and transpiration response to soil water deficit. Field Crops Res., 68: 205-210.

Soltani, A., B. Torabi, E. Zeinali and R. Sarparast, 2004. Response of chickpea to photoperiod as a qualitative long-day plant. Asian J. Plant Sci., 3: 705-708.

Soltani, A., B. Torabi and H. Zarei, 2005. Modeling crop yield using a modified harvest index-based approach: Application in chickpea. Field Crops Res., 91: 273-285.

Soltani, A. and M. Gholipoor, 2006. Teleconnections between El Niño/Southern Oscillation and rainfall and temperature in Iran. Int. J. Agric. Res., 1: 603-608.

Soltani, A., G.L. Hammer, B. Torabi, M.J. Robertson and E. Zeinali, 2006a. Modeling chickpea growth and development: Phenological development. Field Crops Res., 99: 1-13.

Soltani, A., M.J. Robertson and A.M. Manschadi, 2006b. Modeling chickpea growth and development: Nitrogen accumulation and use. Field Crops Res., 99: 24-34.

Soltani, A., M.J. Robertson, Y. Mohammad-Nejad and A. Rahemi-Karizaki, 2006c. Modeling chickpea growth and development: Leaf production and senescence. Field Crops Res., 99: 14-23.

Soltani, A., M.J. Robertson, B. Torabi, M. Yousefi-Daz and R. Sarparast 2006d. Modelling seedling emergence in chickpea as influenced by temperature and sowing depth. Agric. For. Meteorol., 138: 156-167.

Soltani, A. and B. Torabi, 2007. Evaluating yield of chickpea and its stability in dormant seeding (Text in Persian, Abstract in English). Proceedings of 2nd National Symposium of Organic Farming, Oct. 16-17, University of Agricultural Sciences and Natural Resources, Gorgan, Iran, pp: 588-602.

Soltani, A., M. Gholipoor and K. Ghassemi-Golezani, 2007. Analysis of temperature and CO_2 effects on radiation use efficiency in chickpea (*Cicer arietinum* L.). J. Plant Sci., 2: 89-95.

Soltani, E. and A. Soltani, 2008. Climatic changes of Khorasan, north-east of Iran, during 1950-2004. Res. J. Environ. Sci., 2: 316-322.

Tanner, C.B. and T.R. Sinclair, 1983. Efficient Water Use in Crop Production: Research or Re-search? In: Limitations to Efficient Water Use in Crop Production, Taylor, H.M., W.R. Jordan and T.R. Sinclair (Eds.). ASA, CSSA and SSSA, Madison, WI, ISBN-10: 0891180745, pp: 1-27.

Zhai, P.M., A. Sun and F.M. Ren, X. Liu, B. Gao and Q. Zhang, 1999a. Changes of climate extremes in China. Climate Change, 42: 203-218.

Zhai, P.M., Ren, F.M. and Q. Zhang, 1999b. Detection of trends in China's precipitation extremes. Acta Meteorol. Sin., 57: 208-216.

Zhang, X., L.A. Vincent, W.D. Hogg and A. Niitsoo, 2000. Temperature and precipitation trends in Canada during the 20th century. Atmos. Ocean, 38: 395-429.

Zhang, X., K.D. Harvey, W.D. Hogg and T.R. Yuzyk, 2001. Trends in Canadian stream flow. Water Resour. Res. 37: 987-998.