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Future Climate Impacts on Chickpea in Iran and ICARDA

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Abstract: Study the effects of climate change, i.e., increasing temperature (T) and CO_2 concentration (C) and changing rainfall (R), on crop systems could help to develop needed adaptation strategies. Subsequently, these strategies can promote and stabilize crop yield. The effects of two future climate scenarios on chickpea was investigated in a full factorial combination of 4 factors (6 locations×3C×7T×3R). The scenarios were reduction of 10% historic R (rainfed conditions) +525 ppm C + 2°C warmer T (year 2050) and declining of 20% historic R (rainfed conditions) +700 ppm C+4°C warmer T (year 2100). This study was performed for ICARDA (from Syria) and five locations of Iran using CYRUS model. The results indicated that for both scenarios, the differential grain yield of rainfed chickpea will be positive in all locations. Since the differential Harvest Index (HI) tended to be mainly negative, the increase in grain yield was not proportional to increase in biomass. By year 2050, it is expected that the stability of yield to be increased for most locations; however, that of yield would be less stable for Tabriz, Mashhad and ICARDA, but more stable for other locations at year 2100. In irrigated conditions, different scenarios had different effects on biomass, HI and yield stability in all locations. The differential grain yield appeared to be negative [0 (ICARDA) to 18%] for year 2050; this was also true for year 2100 (6.3 to 17.1%). Both the results of factorial combination of factors and of probability of occurring temperatures higher than ceiling temperature suggested that to avoid future yield loss in irrigated conditions, chickpea improvement for heat tolerance is inevitable.

Key words: Chickpea, climate change, CYRUS, yield, harvest index, biomass

INTRODUCTION

There is general agreement for warming the surface air temperature in future. Some reports indicate that higher temperature may increase yield of crops. Higher-temperature-resulted increase in the yield of spring-sown-crops may be attributable to decreased probability of occurring freezing/chilling stress at early stages of growth and development (Rosenzweig and Iglesias, 1998). Based on reports of Van Ittersum *et al.* (2003), the positive effects of moderately elevated temperatures (≤3°C) on grain yield of wheat may be significant in future. This has been attributed to advancement of the grain filling period to a significantly cooler and wetter part of the season allowing crops to produce higher grain yields. On the other hand, most reports confirm the negative effects of higher temperature on crops. As instance, Krishnan *et al.* (2007) found that at all the CO_2 levels (380, 400, 500, 600 and 700 ppm), yield of rice shows declining trend with increasing temperature. Bélanger *et al.* (2002) reported that under predicted warmer temperatures, risks of winter injury to perennial forage crops in eastern Canada will likely increase. This is because of less cold hardening during fall and reduced protective

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snow cover during the cold period, which will increase exposure of plants to killing frosts, soil heaving and ice encasement. The findings of Guerena *et al.* (2001) indicated that in the Southern areas of Spain, warming may lead to a lack of vernalization for future. Ludwig and Asseng (2006) reported that in the Northern part of the Western Australian wheatbelt, higher temperatures will has a negative effect on yield. A major indirect effect of higher temperatures is higher plant water demand due to increased transpiration, which can potentially reduce plant production (Lawlor and Mitchell, 2000; Peng *et al.*, 2004). Some reports indicating that the effect of temperature on crops depends on soil type. For example, it has been found that an increase in annual temperature of up to 3°C has a positive effect on the clay soil (up to 15%) and slightly negative effects on the sandy soil; thereafter, yields decrease substantially on both soil types (up to 40-55% relative to the control) (Van Ittersum *et al.*, 2003). In general, higher temperatures tend to reduce grain yield. This is due to reduced length of the growing period and so less intercepted radiation which results in lower biomass production (e.g., Lawlor and Mitchell, 2000).

It is widely recognized that elevated atmospheric CO_2 can has the increasing effect on crop biomass and possibly on crop yield (e.g., Krishnan *et al.*, 2007). Plants grown at higher CO_2 concentration tend to have a higher leaf water potential which results in reduced drought stress (Wall, 2001). In combination, the effects of warmer temperatures and higher CO_2 concentrations can either increase or decrease plant production and net effect depends on the interactions between these different factors (Ludwig and Asseng, 2006). Findings indicate that higher CO_2 concentration can counteract the negative effects of higher temperatures through a lower stomatal conductance which reduces transpiration (Wall, 2001). For Western Australia, Ludwig and Asseng (2006) found that negative effects of increased temperatures will probably, in almost all cases, be compensated by the positive effects of higher CO_2 concentrations. Lal *et al.* (1998) used the CERES-rice and predicted a 20% decline in rice yields in the Northwestern India due to elevated CO_2 and temperature. Based on findings of Van Ittersum *et al.* (2003) positive effects of a high CO_2 concentration on yield is 3-8% higher under the elevated temperature than under ambient temperature.

The published reports regarding future climate impacts on chickpea are rare. In Maragheh, Iran, the old version of CYRUS has been used for predicting growth and water use of chickpea in future (Soltani and Gholipoor, 2006). Barzegar and Soltani (2007) investigated the effect of future climate on yield of just rainfed chickpea in Northwest of Iran using recent version of CYRUS. This study was aimed to investigate the effects of two future climate scenarios on rainfed and irrigated chickpea in ICARDA (from Syria) and five locations of Iran. The results of this study may help to introduce needed adaptation strategy (s) for promoting and stabilizing chickpea yield in future.

MATERIALS AND METHODS

Model Description

In this study, the CYRUS model was recorded in Qbasic programming language and run to investigate the responses of chickpea to future climate. This model was initially designed by Soltani *et al.* (1999). 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.*, 2004a), 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 effect 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) and optimizing the dormant sowing of chickpea (Gholipoor *et al*., 2006). The soil water balance sub model of this model with some little modifications has been applied for comparative evaluating the climate-related runoff production in slopped farms of Iran (Gholipoor, 2008) and to study the effect of past climate change on runoff in Gorgan, Iran (Gholipoor and Soltani, 2005).

Briefly, in seedling emergence sub model of CYRUS, emergence response to temperature is described by a dent-like function with cardinal temperatures of 4.5 (base), 20.2 (lower optimum), 29.3 (upper optimum) and 40°C (ceiling temperature). Six physiological days (i.e., number of days under optimum temperature conditions; equivalent to thermal time of 94°C days) are required from sowing to emergence at a sowing depth of 5 cm. The physiological day's requirement is increased by 0.9 days for each centimeter increase in sowing depth. Snow cover effect is considered on the basis of daily maximum and minimum temperatures, as presented by Ritchie (1991).

In leaf sub model, cardinal temperatures for nod appearance are 6.0°C for base, 22.2°C for optimum and 31.0°C for ceiling temperature. Leaf senescence on the main stem starts when the main stem has about 12 nodes and proceeds at a rate of 1.67% per each day increase in physiological day (a day with non-limiting temperature and photoperiod). Leaf production per plant versus main stem node number occurs in two phases; phase 1 when plant leaf number increases with a slower and density-independent rate (three leaves per node) and phase 2 with a higher and density-dependent rate of leaf production (8-15 leaves per node).

Phenological development is calculated using multiplicative model that includes a dent-like function for response to temperature and a quadratic function for response to photoperiod. Photoperiod-sensitivity is considered to be different in various cultivars and cardinal temperatures for phenological development are 21°C for lower optimum, 32°C for upper optimum and 40°C for ceiling temperature. The cultivars require 25-31 physiological days from E (emergence) to R1 (flowering), 8-12 from R1 to R3 (pod initiation), 3-5 from R3 to R5 (pod filling), 17-18 from R5 to R7 (pod yellowing) and 6 from R7 to R8 (physiological maturity).

The biomass production is calculated based on extinction coefficient (KS) and radiation use efficiency (RUE). It assumes that KS is not radiation- and plant density-dependent. The RUE assumes to be constant (1 g MJ^{-1}) across plant densities, but not across temperatures and CO_2 concentrations. After correction of RUE for temperature and CO_2 concentration, it is not affected by either solar radiation or Vapor Pressure Deficit (VPD). The partitioning of biomass between leaves and stems is achieved in a biphasic pattern before first-seed stage. After this stage, the fixed partitioning coefficients are used for calculating biomass allocation.

Many simulation models assume linearity of harvest index increases as a simple means to analyze and predict crop yield in experimental and simulation studies (Soltani *et al*., 2005). Despite of these models, the CYRUS model assumes that its increase is biphasic with turning point temperature equal to 17°C. The similar approach has been proved to be appropriate for application in wheat (Soltani *et al*., 2004b).

The relation between total N and total biomass throughout the growth period is based on non-linear segmented model (with two segments/phases). Therefore, the rates of N accumulation during phase 1 and 2 are different and the turning point between two phases of N accumulation is considered 218.3 g biomass m^{-2}. The distribution of N to different parts of plant is calculated using appropriate functions and coefficients.

In soil water balance sub model, daily soil water content is estimated as fraction transpirable soil water (FTSW, which ranges from 0 to 1) to calculate the degree of water limitation experienced by the crop. 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. Soil evaporation is calculated using the two-stage model as implemented in spring wheat model developed by Amir and Sinclair (1991). Stage 1 evaporation occurs when water present in the top 200 mm of soil and FTSW for the total profile is greater than 0.5. Stage 2 evaporation 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 2, evaporation is decreased substantially as a function of the square root of time since the start of stage 2. The calculation of evaporation is returned to stage 1 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.

Locations, Future Climate Scenarios and Calculated Attributes

Six locations with long-term and reliable daily weather data were selected from Iran and Syria for this study. The selected location from Syria was ICARDA (International Center for Agricultural Research in the Dry Areas: 36.01°N, 36.93°E and 284 m asl; weather data set: 1987-2007) and selected ones from Iran were Isfahan (32.67 °N, 51.87 °E and 1600 m asl; weather data set: 1961-2004), Shiraz (29.55°N, 52.60°E and 1488 m asl; weather data set: 1961-2004), Kermanshah (34.32°N, 47.12°E and 1322 m asl; weather data set: 1961-2004), Tabriz (38.13°N, 46.28°E and 1364 m asl; weather data set: 1966-2004) and Mashhad (36.27°N, 59.63°E and 990 m asl; weather data set: 1961-2004). The locations in Iran represent a large geographical area and several climatic zones (Gholipoor, 2008). The cultivars were Arman for Isfahan and Shiraz, Beauvanij for Kermanshah, Jam for Tabriz and Hashem for Mashhad (Soltani *et al*., 2004a) and ICARDA.

The climate scenarios which were simulated covered the range of conditions. For changes in rainfall three different scenarios were used: historic rainfall, 20% declined and 10% increased rainfall; in this procedure, as it was used by Ludwig and Asseng (2006), the number of rainfall events remains equal, but the intensity of each event is changed; although it is not realistic to expect that every event will change in intensity as a result of climate change, this approach is useful because, it shows what the effect is of reduced rainfall using the same inter-annual variation as the historic climate (Ludwig and Asseng, 2006). For the elevated temperature scenarios the daily minimum and maximum temperatures were increased by adding 1, 2, 3, 4, 5 and 6°C. Every climate scenario was run for three different atmospheric CO_2 concentrations: 350 ppm CO_2 concentration at the time when CYRUS model was developed, 525 and 700 ppm. Although all combinations of temperature, rainfall and CO_2 scenarios were included, data presentation and discussing focused on two possible future climate scenarios which are likely to occur around 2050 and 2100. The chosen scenarios were a combination of treatments based on future climate predictions described in Barzegar and Soltani (2007), Koocheki *et al.* (2003) and Ludwig and Asseng (2006). For 2050, the scenario was selected with 525 ppm CO_2, 2°C higher temperature and 10% reduced rainfall. The second climate scenario (2100) was 700 ppm CO_2, 4°C higher temperature and 20% declined rainfall.

The main calculated attributes were biomass, Harvest Index (HI) and grain yield. The value of Coefficient of Variations (CV) was used as index of stability for grin yield. Some additional attributes were also calculated to interpret the response of chickpea to future climate. These attributes were growing period, rainfall across the growing period, biomass at 30 days after sowing, runoff across the growing period, evaporation and cumulated transpiration at 40 days after sowing. In addition, the value of FTSW lower than 0.34 at which the relative transpiration tends to be decreased (Soltani *et al*., 1999) was considered as drought; then, the cumulative distribution functions were made (Purcell *et al*., 2003) to calculate the probability of occurring drought. Based on this fact that 31°C is ceiling temperature for nod (leaf) appearance (Soltani *et al*., 2006c), the mean temperatures higher than 31°C was considered as heat stress for chickpea which is a cool season crop; like drought case, the probability of occurring heat stress across growing period was calculated.

RESULTS AND DISCUSSIONS

The effect of increased temperatures on biomass of irrigated chickpea for 3 atmospheric CO_2 concentrations was presented in Fig. 1 (left-sided column). In each location, the horizontal line indicates the value of biomass for historic temperature and ambient CO_2 concentration. It is obvious that the differential value is positive for biomasses above, but negative for those below the horizontal line. For 1st scenario (year 2050), i.e., 525 ppm atmospheric CO_2 concentration and 2°C warmer

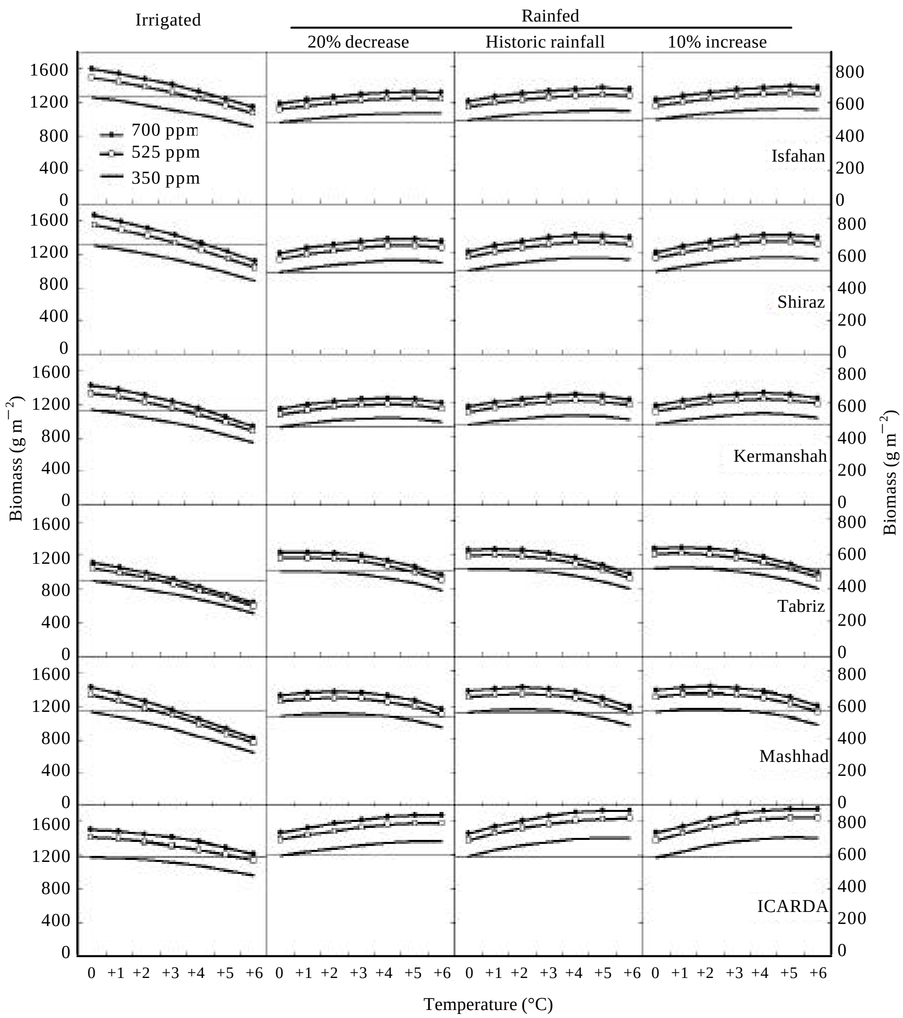

Fig. 1: Effect of increased temperature on biomass of irrigated (left-sided column) and rainfed [three right-sided columns including increased rainfall (10% of historic rainfall: 1st column from right-side), historic rainfall (2nd column from right-side) and decreased rainfall (20% of historic rainfall: 3rd column from right-side) chickpea for three atmospheric CO_2 concentrations. The 1st row from bottom represents a location from Syria (ICARDA: International Center for Agricultural Research in the dry areas) and others from Iran. The horizontal lines indicate the value of biomass for ambient CO_2 concentration and historic temperature

temperature, the differential value of biomass was positively ranged from 3.9 (Mashhad) to 14.4% (ICARDA); for 2nd scenario (year 2100), i.e., 700 ppm atmospheric CO_2 and 4°C increased temperature, that of biomass was +5.2, +1.7, +1.4, -7.9, -7.7 and +14.3% for Isfahan, Shiraz, Kermanshah, Tabriz, Mashhad and ICARDA, respectively. In view point of sensitivity analysis (hereafter generally represents results regarding sensitivity analysis), in all locations, the biomass was consistently, but not proportionally, increased with increasing CO_2 concentration; at all temperatures, the difference between 525 and 700 ppm CO_2 concentration was relatively less than that between 350 and 525 ppm CO_2. Therefore it seems that chickpea tends to have some saturation state at CO_2 concentrations higher than 525 ppm. Although all lines regarding the values of biomass for different CO_2 levels showed decreasing trend with warming the temperature, they were not parallel. Therefore temperature and CO_2 tend to have interaction; the positive effect of CO_2 fertilization appears to be more considerable in less warmed situations. This may be due to well-documented deleterious effects of high temperatures on enzyme activity (Daniel *et al*., 1996) and lipid peroxidation (Liu *et a*.., 2006). The order of locations for magnitude of interaction was as Mashhad> Shiraz> Isfahan> Kermanshah> Tabriz> ICARDA. Considering the horizontal lines, the value of warming at which the positive effect of CO_2 fertilization tends to be neutralized, can be easily interpolated for each location; for example, the stimulating effect of 50% increase in CO_2 concentration (i.e., 525 ppm) tends to be neutralized at +5.3°C for ICARDA, while it is +3.4°C at Isfahan.

The effects of temperature and CO_2 on biomass of rainfed chickpea at 3 different rainfall scenarios were shown in Fig. 1 (three right-sided columns). The effect of rainfall scenarios on biomass appeared to be not considerable; the averaged value of biomass was 615 g m^{-2} for historic rainfall, 598 g m^{-2} for 20% lower rainfall and 623 g m^{-2} for 10% higher rainfalls. In a simulation study for Kermanshah, Iran, Gholipoor (2007) also reported that the biomass of rainfed chickpea tends to show negligible change with increasing rainfall of up to 150% over growing period; he concluded that no response of biomass to increased rainfall is due to no considerable change in soil-stored-moisture. The increase in biomass for year 2050 (and for year 2100) was 23% (33%) in Isfahan, 30 (38) in Shiraz, 26 (34) in Kermanshah, 13 (10) in Tabriz, 17 (18) in Mashhad and 26 (39) in ICARDA. In general, at all locations and rainfall scenarios, it found nearly no interaction between CO_2 and temperature; the increasing/decreasing effect of temperature was almost the same at different CO_2 concentrations. Under 525 and 727 ppm CO_2 concentrations, the average value of biomass over temperature levels and rainfall scenarios was about 15.96 and 22.90% higher, respectively, as compared to 350 ppm CO_2 concentration. In Tabriz, at all CO_2 concentrations and rainfall scenarios, the value of biomass nearly showed no change with increasing the temperature by 1°C, but subsequently changed inversely with more warming the temperature. In Isfahan and Shiraz, it was found nearly close directed-relation between biomass and temperature up to about +4°C; with incrementing temperature from 4°C, biomass appeared to show decreasing trend in Shiraz, while almost plateau state in Isfahan. In Kermanshah, +4°C tended to be nearly turning point; biomass was found to have inversed-change over temperatures above, but directed-change over those below the turning point. Similar situation was nearly true for Mashhad (turning point was almost +2°C). In ICARDA, the biomass showed upwardly-trend with incrementing the temperature up to +4°C, then plateau state.

In all tested locations, it is expected that the probability of occurring drought at growing period of rainfed chickpea to be increased by years 2050 and 2100, due to decreased rainfall. However, the differential probability of occurring FTSW<0.34 (drought) at vegetative and reproductive stages appeared to be sensibly positive in Isfahan, but negative in Shiraz, Kermanshah, Mashhad, ICARDA and Tabriz (Table 1). These probable future-climate-resulted favorable wetter conditions for last five locations may be due to decline in growing period (Table 1) and as a result shifting vegetative and reproductive stages to period with more rainfall (Table 1) and to more rapid canopy-closure (Table 1) resulted decrease in loss of water by runoff (Table 2; it should be noted that a little part (about one

Table 1: The differential values (%) of some attributes in rainfed conditions for year 2050 (10% reduced historic rainfall, 525 ppm atmospheric CO_2 and +2°C warmer temperatures) and year 2100 (20% declined historic rainfall, 700 ppm atmospheric CO_2 and +4°C warmer temperatures)

	#Probability of occurring FTSW<0.34 at vegetative stage		Probability of occurring FTSW<0.34 at reproductive stage		Growing period		Rainfall across reproductive stage		Biomass at 30 days after sowing	
Location	2050	2100	2050	2100	2050	2100	2050	2100	2050	2100
Isfahan	0.4	2.5	1.3	0.9	-6.8	-12.2	2.8	2.0	162	410
Shiraz	-0.2	-1.7	-0.4	-0.2	-6.2	-10.9	0.4	0.1	125	285
Kermanshah	-1.9	-1.5	-1.3	-2.0	-7.1	-12.3	0.4	0.2	93	182
Tabriz	-0.7	-1.7	-2.7	-7.6	-7.0	-11.9	11.7	7.0	53	81
Mashhad	-0.2	-1.8	-1.3	-2.1	-6.0	-10.2	5.3	3.3	70	114
ICARDA	-2.3	-2.0	-0.4	-0.1	-6.5	-11.9	4.7	4.0	106	340

#: FTSW is fraction transpirable soil water; ICARDA (International Center for Agricultural Research in the dry areas) is a location from Syria and others from Iran

Table 2: The differential values (%) of some attributes in rainfed and one attribute in irrigated conditions for year 2050 (10% reduced historic rainfall (rainfed conditions), 525 ppm atmospheric CO_2 and +2°C warmer temperatures) and year 2100 (20% diminished historic rainfall (rainfed conditions), 700 ppm atmospheric CO_2 and +4°C warmer temperatures)

	Runoff		Evaporation		Cumulated transpiration at 40 days after sowing		#Probability of occurring TMP >31°C		Probability of occurring TMP>31°C for irrigated	
Location	2050	2100	2050	2100	2050	2100	2050	2100	2050	2100
Isfahan	-27.4	-60.3	-14.2	-22.2	132	380	5.8	7.8	11.9	20.7
Shiraz	-35.3	-58.2	-13.0	-20.1	104	233	7.4	11.7	12.2	16.6
Kermanshah	-25.6	-47.5	-15.0	-17.5	77	111	12.9	23.7	18.9	36.0
Tabriz	-36.1	-58.6	-7.4	-12.8	44	61	15.1	25.8	16.5	29.6
Mashhad	-41.0	-65.4	-5.7	-13.4	50	99	16.1	25.6	18.8	30.9
ICARDA	-33.7	-60.4	-12.1	-19.6	89	260	11.1	19.0	15.4	27.0

#: Daily Mean Temperatures (TMP) higher than 31°C across reproductive stage; ICARDA (International Center for Agricultural Research in the dry areas) is a location in Syria and others in Iran

tenth) of the decrease in runoff and evaporation is due to decline in rainfall) and by evaporation (Table 2). It seems that the difference between Isfahan and other locations for differential probability of occurring drought may be due to differential growth of plant at early stages, which was more considerable in Isfahan, as compared with other locations (Table 1), it caused that the differential adsorption, say evacuation, of soil water at early stages of growth and development to be more huge in Isfahan than in others (Table 2). Therefore for future scenarios, as it was mentioned, occurrence of drought tends to be sensibly increased in Isfahan, but decreased in other locations.

In conventional agriculture, the soil-stored water at winter tends to be considerably lost at sowing date of chickpea (spring). This is due to deeply plowing the soil by moldboard plow and consequently more exposure of more moistened soil of lower horizons to sun radiation and wind. Therefore in regions with winter (non-growing season)-dominant rainfall, like tested locations, the reproductive growth of rainfed chickpea is mainly dependent on soil water content (precipitation) at growing period. So, any change of soil water content at growing period and especially at reproductive stage may have a drastic effect on HI. Based on this explanation and on above mentioned differential probabilities of occurring drought, it is expected that the differential HI of rainfed chickpea by years 2050 and 2100 to be negative in Isfahan, but positive in other locations. However, it was negligible in Tabriz, but negatively considerable for other locations, including Isfahan (Fig. 2). This finding imply that in addition to soil water content, other factors including temperature may be effective on HI in future climate of tested locations. The suppose regarding the effectiveness of higher temperatures for decreasing the HI might be more confirmed by the following issue. For most location-scenario

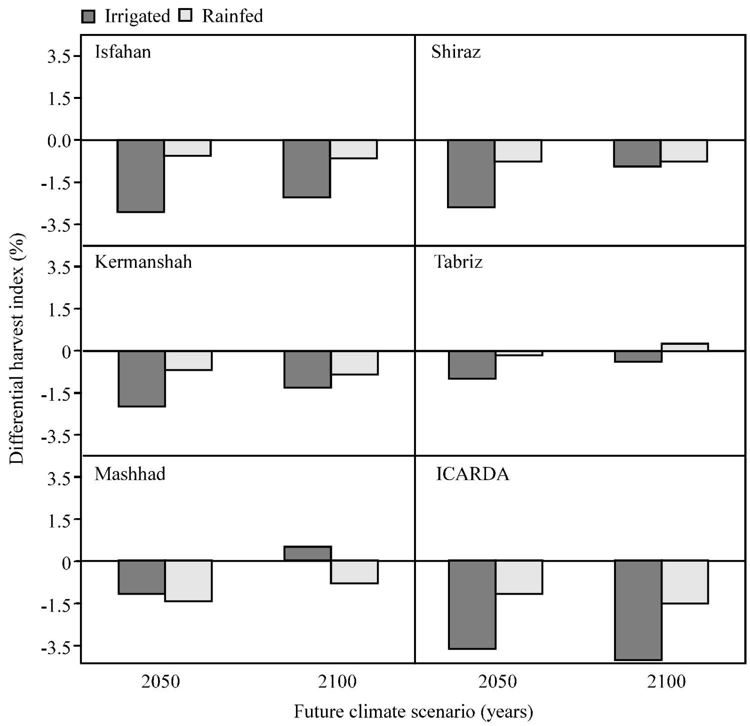

Fig. 2: The differential harvest index of rainfed and irrigated chickpea for two possible future climate scenarios [1st scenario (year 2050): 10% decrease in historic rainfall (rainfed conditions), 525 ppm atmospheric CO_2 and +2°C; 2nd scenario (year 2100): 20% decline in historic rainfall (rainfed conditions), 700 ppm atmospheric CO_2 and +4°C]. ICARDA (International Center for Agricultural Research in the Dry Areas) is a location from Syria and others from Iran

combinations (only Mashhad-scenario combinations are exception), the value of increase in probability of occurring heat stress (Table 2) was more considerable for irrigated (i.e., no experiencing drought stress) than for rainfed conditions; consequently (say expectedly), it was true for that of decrease in HI (Fig. 2). The increase and/or decrease in HI of rainfed chickpea may be determined by predominance of favoring and/or deleterious effects, respectively. Tabriz and Mashhad appeared to have the same considerable (highest) positive differential probability of occurring heat stress at reproductive stage of rainfed chickpea for both scenarios (Table 2). On the other hand, these locations were dissimilar for deriving benefit from decreased drought at reproductive stage (Table 1); the value of minus differential probability of occurrence of drought was higher in Tabriz (it was also highest) compared to Mashhad (2nd highest). Therefore, the negligibility of differential HI of rainfed chickpea in Tabriz may be due to the fact that harmful effects of increased heat stress tend to be counterbalanced by favoring effects of decreased drought; in Mashhad, the predominance of deleterious effects over favoring effects might cause that the differential HI to be negated. The lowest positive differential probability of occurring heat stress at reproductive stage of rainfed chickpea was found for Isfahan. As a result, decrease in HI for future rainfed conditions of Isfahan may be attributable mainly to worsened conditions regarding increased drought. Nearly similar situations were also found for other locations.

In Isfahan, Shiraz and Kermanshah the difference between two scenarios was negligible for HI of rainfed chickpea (Fig. 2). These locations appeared to have nearly the same value of differential HI (about -0.9%). In Mashhad and ICARDA, the minus value of differential HI tended to be different for two scenarios; in Mashhad, it was more sensible for year 2050, compared to year 2100; in ICARDA, relatively more decline in HI was devoted to year 2100. For better evaluating the response of HI to combinations of rainfall, temperature and CO_2, Fig. 1 was prepared for HI (not shown). This was also done for other attributes which are discussed latter. In general, the differential HI of rainfed chickpea for both enhanced CO_2 concentrations was minus over less-warmed temperatures, but positive over more warmed temperatures; the inflection temperature (the temperature at which the sign of differential HI appears to change; say turning point) for 50% increased CO_2 (and for 100% increased CO_2 concentration) was 4°C (5°C) in Isfahan, 3 (5) in Shiraz, 3 (5) in Kermanshah, 2 (3) in Tabriz, 3 (5) in Mashhad and 5 (5) in ICARDA. The differential HI was ranged from -3 to +3% over all CO_2-temperature-rainfall combinations.

Results regarding irrigated chickpea indicated that HI will be diminished by about 1.2% (in Tabriz) to 3.9% (ICARDA) for year 2050 (Fig. 2). For other scenario, the differential HI will be positive in Mashhad (0.4%), but negative in other locations. As it was mentioned previously, this decrease may be mainly due to increased heat stress. In locations of Iran the value of change in HI was lower for year 2100 than for year 2050; while in location of Syria that of change appeared to be more considerable for year 2100, when compared with value of change for year 2050. Generally, for all CO_2 levels, that of HI was consistently increased with warming temperature. Averaged over temperature levels, that of HI inversely changed with changing CO_2 level.

The grain yield is determined by the value of biomass and HI. In all locations, the differential grain yield of rainfed chickpea appeared to be positive for both scenarios (Fig. 3). Barzegar and Soltani

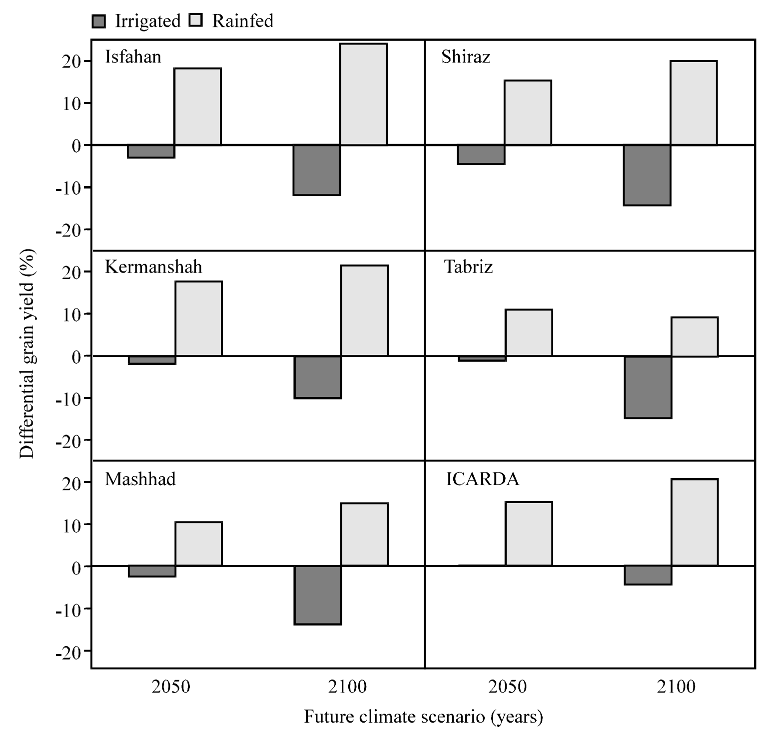

Fig. 3: The differential grain yield of rainfed and irrigated chickpea for two possible future climate scenarios [1st scenario (year 2050): 10% decline historic rainfall (rainfed conditions), 525 ppm atmospheric CO_2 and +2°C; 2nd scenario (year 2100): 20% decrease in historic rainfall (rainfed conditions), 700 ppm atmospheric CO_2 and +4°C]. ICARDA (International Center for Agricultural Research in the Dry Areas) is a location from Syria and others from Iran

(2007) also reported about 26% increase in yield of rainfed chickpea for Northwest of Iran by year 2100. The order of locations for magnitude of differential grain yield was as Kermanshah> Isfahan> ICARDA> Shiraz> Tabriz> Mashhad by year 2050 and as Isfahan> Kermanshah> ICARDA> Shiraz> Mashhad> Tabriz by year 2100. Generally, among locations, only Tabriz appeared to have negative differential averaged grain yield of rainfed chickpea over rainfall scenarios just for some CO_2-temperature combinations (combination of 50% increased CO_2 concentration and temperatures +5 and +6°C and of 100% enhanced CO_2 concentration and temperature +6°C). Among rest locations, ICARDA and Mashhad had relatively more considerable positive differential grain yield for all combinations of increased CO_2 and warmed temperatures.

By year 2050, the differential grain yield of irrigated chickpea found to be negligible and zero in Tabriz and ICARDA, respectively, but negatively considerable (2.3 to 5.7%) in others (Fig. 3). For scenario 2100, it tended to be minus for all locations; the values varied between 6.3% (ICARDA) and 17.1% (Shiraz). Generally, in all locations, the favoring effect of 50% increased CO_2 concentration on grain yield of irrigated chickpea appeared to be dominated over the deleterious effect of just 1 °C warmed temperature; therefore, the differential grain yield found to be positive for combination of mentioned CO_2 concentration and named temperature, but negative for combinations of named CO_2 concentration and temperatures +2 to +6°C. With some minor exceptions, this was also true for favoring effect of 100% increased CO_2 concentration. The decline in grain yield with warming the temperature is in agreement with findings for other crops, including rice (Krishnan *et al*., 2007).

The lower fluctuation, say stability, is one of the important aspects of grain yield in rainfed conditions. For 1st scenario, the differential CV was positive in Tabriz (3.8%), while it appeared as negative at other locations (0.7 to 4.5%). For other scenario, it tended to be positive in Tabriz (9%), Mashhad (1.5%) and ICARDA (0.6%), but minus in other locations (2.2 to 4.9%). The reports for northwest of Iran have indicated that the stability of grain yield of rainfed chickpea will be diminished by year 2100 (Barzegar and Soltani, 2007). Generally, in each location, the interaction of CO_2 levels with temperature appeared to be imperceptible for averaged CV over three rainfall scenarios. The difference between CO_2 levels for CV was negligible in Tabriz, but considerable in rest locations; in these five locations, the CV decreased consistently but not proportionally with heightening CO_2 concentration; the difference between 700 and 525 ppm CO_2 was lower as compared to that between 525 and 350 ppm. In Isfahan and ICARDA, CV was not changed with changing temperature. In other locations, it appeared to show inversed change over less warmed temperatures (+1 to +3°C), but directed change over more warmed temperatures (+4 to +6°C).

The results regarding irrigated conditions indicated that for 1st scenario, the differential CV was minus in Isfahan (0.7%), but positive in other location (0.9 to 6.2%). For 2nd scenario, it was positive for all locations (0.7% in Isfahan, 7.3% in Shiraz, 8.8% in Kermanshah, 16.8% in Tabriz, 7.0% in Mashhad, 3.2% in ICARDA). Generally, CV appeared to show increasing trend with warming. With some negligible exceptions, it was also stimulated with enhancing CO_2 concentrations, especially in Tabriz.

CONCLUSION

The results indicated that for both scenarios, the differential grain yield of rainfed chickpea will be positive in all locations. Since, the differential harvest index tended to be mainly negative, the increase in grain yield was not proportional to increase in biomass. By year 2050 it is expected that the stability of yield to be increased for most locations; however, it would be less stable for Tabriz, Mashhad and ICARDA, but more stable for rest locations at year 2100. In irrigated conditions, different scenarios had different effects on biomass, harvest index and yield stability in all locations. The differential grain yield appeared to be negative [0 (ICARDA) to 18%] for year 2050; this was also true for year 2100 (6.3 to 17.1%).

Both the results of sensitivity analysis and of probability of occurring mean temperatures warmer than ceiling temperature indicated that the main reason for future yield loss in irrigated conditions may be due to increased heat stress. Therefore, improvement of chickpea varieties for heat tolerance is required to be adapted next to agronomical practices, including earlier sowing date. However, environmental conditions like rainfall have restrictive effect on sowing date. Moreover, chickpea is not a good responder to different sowing dates since it respond to photoperiod qualitatively (Soltani *et al*., 2004a). Thus improvement of chickpea varieties that have a low sensitivity to photoperiod might be suggested as an alternative strategy. These improved varieties can be used in dormant sowing technology. In this technology, the crop is sown during late autumn or early winter after temperatures become too low for seed germination to occur until the following spring; then, it emerges as soon as temperatures permit and no time is lost in spring for seedbed preparation and sowing. Earlier studies have suggested that dormant sowing can have a great role on seedling emergence by about 17-22 days (Gholipoor *et al*., 2006; Soltani *et al*., 2006d). This early seedling emergence can improve the overall yield via winning the competition with weeds (Lemerle *et al*., 1996 cited in Rebetzke and Richards, 1999), better water use efficiency through both water availability in early stages and lower vapor pressure deficit (Condon *et al*., 1993; Tanner and Sinclair, 1983).

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