Effects of climate change on growth criteria and yield of sunflower and chickpea crops in Iran

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ABSTRACT: Yield and growth criteria of irrigated and rainfed sunflower *Helianthus annus* and chickpea *Cicer arientinum* were studied under simulated climate change for Tabriz in Iran. Monthly average temperature and rainfall under doubling CO_2 were predicted using Goddard Institute for Space Studies (GISS) and Geophysical Fluid Dynamics Laboratory (GFDL) models. The effects of climatic change on crop growth period, yield components and water requirements of those crops were evaluated by a crop simulation model (OSBOL). Based on GISS and GFDL predictions, with doubling CO_2 concentration, mean annual temperature for Tabriz increased by 4.6 and 4.3°C, respectively. The results obtained by GISS showed that doubling CO_2 will lead to an increase in mean temperature of 3.7°C, and a 40% increase in mean rainfall, during the first 5 mo of the year. However, GFDL predicted an increase of 4.7°C in mean temperature and a reduction of 12% in mean rainfall during the first 5 mo of the year. According to OSBOL under GDFL predictions, the period from sowing to maturity and harvest index were reduced by climate change, whereas yield, biomass and water requirement for irrigated sunflower were increased. The biomass for rainfed sunflower increased, while days to maturity and harvest index were reduced. Yield predictions of OSBOL based on GISS contrasted with those based on GFDL. Doubling CO_2 caused a reduction in days to maturity, biomass, yield and water requirements for irrigated chick pea. The number of days to maturity for rainfed chickpea was reduced and harvest index, biomass and yield were increased due to climate change.

KEY WORDS: Climate change · Crop productivity · Dry matter · Environment · Rainfall · Simulation · Yield

1. INTRODUCTION

The impacts of climate change on agriculture are likely to result from the effects of rising CO_2 on plant growth, warmer and drier conditions, changes in wind speed, insect and plant disease pressures, and many more subtle changes resulting from altered interactions among components of crop agro-ecosystems (Smith & Almaraz 2004); however, those impacts which cause losses in crop yield have generally been ignored (Lim et al. 2004, Scherm 2004). Increasing CO_2 and other greenhouse gases are likely to have serious implications for global climate systems and to cause a series of novel environmental changes, predominantly through anthropogenic activities (Allen 1990, IPCC 2001, McMichael 2001, Centritto & Loreto 2005). Increasing CO_2, and consequently temperature, is likely to differentially affect all aspects of plant growth, development and function (Centritto & Loreto 2005) differently according to the plant species and geographical location. Major effects of elevated atmospheric CO_2 concentrations are the enhancement of CO_2 diffusion into leaves and an increase in the rate of photosynthesis, especially in C_3 plants, over a wide range of radiation intensities, and despite decreasing stomatal conductance (Lawlor & Mitchell 1991). Elevated CO_2 and temperatures affect plant growth and the water balance in a complex way, sometimes compensating for drought, sometimes aggravating it (Kimball et al. 2002).

In general, C_3 species can benefit more by the rise in CO_2 in terms of carbon and water balance under well–watered conditions, while C_4 species can benefit from drier environments (Jarvis et al. 1999). Although increase in atmospheric CO_2 may improve plant water use efficiency (WUE), reduced precipitation and increased evapotranspiration losses negatively affect the availability of water for irrigation practices, and ongoing climatic changes could result in a drier environment in semi-arid regions such as Iran. A reduction in water availability would negatively affect crop production even in drought tolerant species. Plant response to a future drier environment with high levels of CO_2 concentration will depend on the balance between the benefits obtained by increased WUE and the real extent of drought (Chartzoulakis & Psarras 2005). Despite contradictory results on the effect of elevated CO_2 on plant respiration, it is clear that the future increase of temperature will enhance carbon losses from respiration/ photorespiration which could have an adverse effect on crop production through net photosynthesis (Taiz & Zeiger 1991).

Curry et al. (1990) simulated the effects of climate change on corn and soybean for the SE USA and found that yield of these crops under rainfed conditions was reduced by 50% due to climate change. Under irrigated conditions, however, yield of corn was reduced by 20% and that of soybean increased by 14%. In the same simulation, it was concluded that water requirements for both crops was increased. Sinclair & Rawlins (1993) also found that yield of corn was not sensitive to climate change, while climate change had a significant positive effect on soybean yield. The contradictory results seem to be due to the wide range of models used by different authors and also diverse climatic conditions under which the models were tested.

Climate change in developing countries is expected to cause health problems and problems of access to adequate food, clean water and other resources, and thereby climate could be a vital factor (Pachauri 2004). Productivity of agricultural systems in Iran is very sensitive to interannual variations in environmental factors, because the ecophysiological factors affecting crop production are not generally very suitable for plant growth and development in most of the country. Crop yield in Iran varies from year to year, largely as a result of highly variable weather conditions, and therefore there is an increasing concern about changes in climate and the combined effects of these changes on crop production. To address this concern, several studies were carried out to predict the potential impacts of climate change on crop production in different areas of Iran. The purpose of the present study was to investigate the effects on climatic factors of doubling CO_2 concentration, and its consequences on the growth and development of sunflower and chickpea under irrigated and rainfed conditions.

2. MATERIALS AND METHODS

General Circulation Models (GCMs) are the most reliable means of predicting climate changes (Curry et al. 1990, Matthews et al. 1994, Schmidt et al. 2004). Two GCMs including the Goddard Institute for Space Studies model (GISS; Russell et al. 1995) and the Geophysical Fluid Dynamics Laboratory model (GFDL; Manabe et al. 1991, 1992) were used to simulate changes in temperature, rainfall, radiation and presumed doubling CO_2 concentration.

The observed data along with the data predicted by GISS and GFDL were used to study the effects of climate changes on growth and development of sunflower and chickpea. Therefore, 3 series of data were obtained: (1) long term observed data, (2) predicted data based on GISS and (3) predicted data based on GFDL. Coefficients obtained from these models were applied to a mean of 30 yr climatic data (1965–1995) for the Tabriz area of Iran.

Direct output from GCMs is inadequate for regional scale impact analysis due to the coarse spatial resolution of GCMs. To overcome these difficulties and to provide useful local or regional scale climate scenarios for impact modeling, techniques such as pattern scaling, regional climate models (RCMs), and statistical downscaling have been proposed. Statistical downscaling was the technique adopted for this study. This method seeks to establish empirical relationships between observed large-scale variables, such as atmospheric pressure or geopotential heights, and an observed climate time series, such as temperature, precipitation or radiation. The use of variables for the upper layers of the atmosphere is based on the assumption that GCMs simulate upper air variables more accurately than surface variables (such as precipitation) resolved by large GCM grid sizes (Wilby & Wigley 2000). As a consequence, the relationships between upper air and surface variables provide transfer functions which can then be applied to output data from GCMs for future time periods (Karl et al. 1990). On this basis, future climate scenarios can be generated at a regional scale, while it is assumed that the derived relationships will remain stable under climate change conditions. Using this method, the reanalyzed data was regridded to the GCM output grid resolution. Climate change scenarios were adapted from IPCC IS95a emission scenario (IPCC 2001). This involves a 1% yr^{-1} rise in radiative forcing, but no consideration of tropospheric ozone, with doubling CO_2 concentration by 2100. This scenario has been deemed suitable for prediction of climate change impacts on Iranian agriculture (Koocheki et al. 2003). The resulting datasets were then used to generate climate scenar-

ios for 2 different periods: 1965–1995 (baseline), and 2065–2095 (2080). The difference between the modeled-future (2080) and modeled-current (baseline) scenarios was calculated and added to the baseline observations to estimate a future climate scenario. Application of statistical downscaling of GCM predictions in Iran used in this study is described in detail by Koocheki et al. (in press).

We evaluated the effects that change in climatic parameters have on growth and development of sunflower and chickpea under climate conditions of Tabriz. For this purpose a simplified model (OSBOL) was developed (Koocheki et al. 1999). This model is based on the following principles:

Phenological development. To quantify crop development, heat period concept was used. In the model the accumulated daily heat period was calculated for each simulated day as follows:

$$DTT = 0 \qquad\qquad T < TB \qquad\qquad (1)$$

$$DTT = T - TB \qquad TB < T < TO \qquad (2)$$

$$DTT = T - TO \qquad TO < T \qquad\qquad (3)$$

where DTT is daily heat period in terms of degree days, T is mean daily temperature, TB is base temperature for crop development, and TO is optimal temperature for plant development. Crop development stages were described by a dimensionless variable (DVS) which has the value 0 at seedling emergence, 1 at flowering and 2 at maturity. DVS is obtained by integration of developmental rate (DVR, d^{-1}). DVR is the reciprocal of the required length of each given stage of development and it is calculated for flowering in sunflower and chickpea as follows:

$$DVR = DTT / TTEE \qquad\qquad (4)$$

where TTEE is required heat period from emergence to flowering. However, after flowering DVR is calculated as follows:

$$DVR = DTT / (TTME - TTEE) \qquad (5)$$

where TTME is heat period requirement from emergence to maturity. DVR is corrected for moisture deficit.

Leaf area. In the initial stages of growth, heat is the main determinant of leaf expansion and providing there is no moisture limitation, leaf area grows exponentially with heat accumulation and can be calculated using the following formula:

$$LAI = PDEN \times LAO \times EXP (RLER \times TT) \qquad (6)$$

where LAI is leaf area index, PDEN is plant density (ind. m^{-2}), LAO is seedling leaf area at the time of emergence, and TT is heat period.

After the end of the exponential stage, leaf area growth rate is reduced (due to shading and inadequate photosynthesis). Daily leaf expansion rate (GLAI) is calculated by:

$$GLAI = LFGR / SLW \qquad\qquad (7)$$

where LFGR is the dry matter allocated to leaves (g m^{-2} d^{-1}) and SLW is specific leaf weight (g m^{-2}).

To calculate the rate of leaf senescence, a parameter for senescence (LDR) was used which was a function of temperature, shading and moisture stress. For a given day, the amount of LAI lost (DLAI) is calculated by:

$$DLAI = LAI \times LDR \qquad\qquad (8)$$

Dry matter production and allocation. Daily dry matter produced is the product of photosynthetically active radiation (PAR, MJ m^{-2}) and radiation use efficiency (RUE, g MJ^{-1}).

$$IPAR = PAR \times (1 - e^{(-K \times LAI)}) \qquad (9)$$

$$DBP = IPAR \times RUE \qquad\qquad (10)$$

where IPAR is intercepted photosynthetically active radiation, K is the extinction coefficient for PAR and DBP is daily biomass produced. RUE is corrected for development stage and for heat and water stress. DBP is allocated to plant parts such as leaves, stem and harvestable yield. The partition coefficient is a function of developmental stage and water stress. Repartitioning of dry matter from vegetative organs to storage organs was simulated based on the assumption that, at the time of filling of storage organs, the part of the stem biomass which is composed of nonstructural compounds is allocated to these organs.

Soil water balance. Soil is usually assumed to consist of 2 layers, the upper part having a depth of around 20 cm. At the time of seedling emergence the depth of the lower layer is equal to that of the upper layer, but after seedling emergence and root elongation this depth increases. For a given day, the amount of water in the upper and the lower layer is calculated by:

$$ESW(t) = ESW(t - 1) + IRGW - E - TRI - D \qquad (11)$$

$$ATSW (t) =$$
$$ATSW (t - 1) + I + IRGW + NEWAT - E - TR - D \qquad (12)$$

where ESW is the amount of water extracted from the upper layer, I is the amount of water infiltrated, IRGW is the amount of irrigated water, E is the evaporation, TRI is the part of the upper layer soil water lost through transpiration, TR is the total transpiration, ATSW is the amount of water in soil subjected to transpiration, NEWAT is the amount of water which has been infiltrated due to facilitation through root proliferation and D is the amount of water lost to deeper soil layers.

3. RESULTS AND DISCUSSION

3.1. Effect of doubling CO_2 on temperature and rainfall in Iran

Since GFDL performed more effectively than GISS over the whole country, the former model was used. The predicted results for temperature and rainfall in different locations of Iran are presented in Table 1. The temperature rise varied between 3.8°C for Bandar-Abbas in the south of Iran and 4.3°C for Orumiah in the northwest. These places are located in 2 climate extremes, and yet the difference in predicted temperatures was only 0.5°C. In most of the locations, the predicted temperature rise was >4°C, which is in an acceptable range for the country. Changes in rainfall predicted with a doubling of CO_2 were between –0.2% in the north (Ardabil) and 14.6% in central and SE Iran (Arak and Zahedan, respectively). Ardabil was the only location where a rainfall increase was not expected.

3.2. Estimate of climate changes in Tabriz

Prediction for Tabriz was made on a monthly basis by using GISS and GFDL (Table 2, Fig. 1). With dou-

Table 1. Effect of doubling CO_2 concentration on mean annual temperature and rainfall in different areas of Iran (predicted by Geophysical Fluid Dynamics Laboratory model [GFDL])

| City	Δ temperature (°C)	Δ rainfall (%)
Arak	4.2	14.6
Ardabil	4.2	–0.2
Orumiah	4.3	0.9
Isfahan	4.3	13.9
Ahvaz	4.1	1.9
Ilam	4.2	11.3
Bandar-e Abbas	3.8	9.8
Bushehr	4.4	7.6
Tabriz	4.3	1.1
Tehran	4.2	12.6
Khorram Abad	4.2	13.6
Rasht	4.2	3.4
Zahedan	3.9	14.6
Zanjan	4.2	5.3
Semnan	4.2	14.1
Sanandaj	4.2	8.4
Sari	4.1	11.5
Shahr-e-kord	4.3	14.1
Shiraz	4.1	10.0
Kerman	4.1	14.2
Kermanshah	4.2	13.0
Gorgan	4.1	10.2
Mashhad	4.1	12.8
Hamadan	4.2	11.7
Yasouj	4.2	10.9
Yazd	4.3	13.3
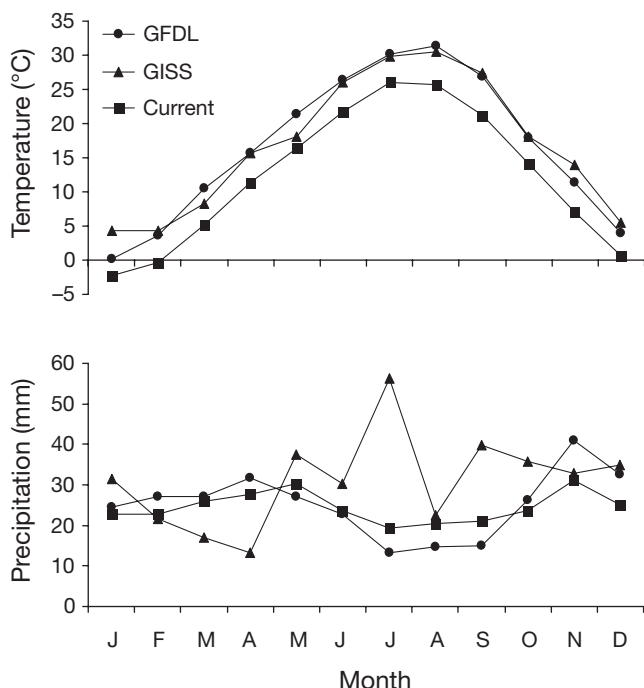
Fig. 1. Effect of doubling CO_2 concentration on mean annual temperature and rainfall using Goddard Institute for Space Studies (GISS) and Geophysical Fluid Dynamics Laboratory (GFDL) models for Tabriz

bling CO_2 concentration, mean annual temperature for Tabriz was predicted to increase by 4.6 and 4.3°C, based on GISS and GFDL, respectively. Temperature increase varied according to season, and depended on the model used. Predictions made by GISS showed a temperature increase in the autumn and winter, whereas GFDL predicted a temperature increase during spring and summer. Temperatures in the first 5 mo of the growing season (April to August) were predicted to increase by 3.7 and 4.7°C based on GISS and GFDL, respectively.

Predictions of rainfall change were 32 and 1%, for GISS and GFDL, respectively. GISS predicted an increase in the amount of rainfall with a more consistent distribution in spring and summer, whereas GFDL predicted no changes in the amount of rainfall, but rather a change in the pattern of rainfall in spring and summer. Since sowing date for rainfed crops in this area coincides with the beginning of spring, the prediction of GFDL indicated an increase in the soil moisture level, but at the same time the effectiveness of rainfall is less than in autumn. A 48 and 8% decrease in rainfall (based on GISS and GFDL, respectively) were predicted for the first 4 mo of the growing period

(April to July); while rainfall in the 6 mo prior to planting was predicted to increase by 16 and 17% (GISS and GFDL, respectively).

3.3. Effects of climate change on growth criteria under irrigated conditions

Doubling of the CO_2 concentration caused a reduction in growth period for sunflower and chickpea (Table 3). These reductions were about 14 and 18% (GISS and GFDL, respectively) for sunflower and 8 and 12% (GISS and GFDL, respectively) for chickpea. Since temperature is the main determinant of the length of growth period, the reduction in growth period predicted by the models could be attributed to increase in temperature. Lower LAI in chickpea might be due to the direct effect of increasing CO_2 or its indirect effects through changes in temperature and rainfall. However, these results were not observed for sunflower. This contradictory result could be attributed to different canopy criteria of these crops. Sunflower has a thermophilous habit helix arrangement and it can continue to expand its leaves even in the predicted climatic conditions. It is also thought to increase its rate of photosynthesis in response to rising CO_2 (Allen 1990, Kimball & Idso 1983). Crop growth rate (CGR) for chickpea was changed by –5 and 1% (GISS and GFDL, respectively). These values were 52 and 63% for sunflower. This could also be associated with the growth criteria of sunflower and particularly LAI mentioned earlier.

Climate change reduced the biological yield of chickpea, while increasing it in sunflower. Since biological yield is a function of interactive effects of growth period and CGR, reduction in biological yield due to stable CGR and climate-change-related reduction in growth period is justified. In sunflower the magnitude of increase in CGR is very high, which could compensate for the reduction of growth period and also increase biological yield. Economic yield of these crops showed the same trend as biological yield. Economic yield showed a reduction of 13 and 8% for chickpea and an increase of 16 and 24% for sunflower predicted by GISS and GFDL, respectively (Table 3).

3.4. Effects of climate change on growth criteria under rainfed conditions

Doubling CO_2 concentration and its consequences with regard to temperature reduced the maturation period of both crops under rainfed conditions (Table 4). LAI showed the same pattern of changes as under irrigated conditions. However, under rainfed conditions, the reduction in LAI for chickpea was smaller and the increase for sunflower was higher than for irrigated conditions. This could be attributed to the shorter growth period under rainfed conditions (approximately 20 d less), and therefore more favorable conditions for the expansion of leaves during growing seasons. Positive effects of climate change for both species under rainfed, as compared to irrigated, crops were more pronounced for photosynthesis than LAI. The magnitude of increase in CGR predicted by GISS and GFDL were 34 and 46% for chickpea and 54 and 91% for sunflower, respectively (Table 4). Since the

Table 2. Effect of doubling CO_2 concentration on mean annual temperature and rainfall using Goddard Institute for Space Studies (GISS) and GFDL models for Tabriz

Month	Δ temperature (°C)			Δ rainfall (mm)		
	Current	GISS	GFDL	Current	GISS	GFDL
1	–2.2	4.2	0.1	22.7	31.4	24.5
2	–0.3	4.2	3.5	22.7	21.6	27.1
3	5.0	8.3	10.4	26.0	16.9	27.0
4	11.4	15.6	15.6	27.7	13.3	31.6
5	16.4	18.1	21.4	30.3	37.3	27.0
6	21.8	25.9	26.4	23.7	30.3	22.7
7	26.1	29.8	30.1	19.3	56.3	13.3
8	25.6	30.4	31.4	20.5	22.5	14.5
9	21.2	27.3	26.8	21.0	39.8	14.9
10	14.1	18.1	17.9	23.6	35.9	26.2
11	7.0	13.9	11.3	31.2	32.7	40.8
12	0.7	5.4	4.0	24.9	34.9	32.4

Table 3. *Helianthus annus* and *Cicer arientinum*. Effects of doubling CO_2 on changes (%) in the crop criteria for irrigated chickpea and sunflower, predicted by GISS and GFDL. LAI: leaf area index; CGR: crop growth rate

	Chickpea			Sunflower		
	Current	GISS	GFDL	Current	GISS	GFDL
Days to maturity	100	91.6	88.3	100	86.2	82.1
LAI	100	80.0	79.1	100	121.9	120.6
CGR	100	95.0	101.4	100	152.2	162.6
Evapotranspiration	100	79.4	18.5	100	102.7	103.9
Irrigation required	100	70.3	74.9	100	103.0	105.2
Biological yield	100	87.1	89.5	100	131.2	133.5
Grain yield	100	87.2	91.8	100	116.2	123.7
Harvest index	100	100	101.5	100	88.3	92.2

increased percentage of CGR is more than the reduction in growth period, the biological yield would increase (see Table 4). Harvest index for chickpea was increased (for GISS and GFDL, respectively) by 21 and 47%, while values for sunflower showed a reduction of 28 and 11% (Table 4). This reduction is probably due to unfavorable growth conditions during the seed filling period of sunflower. It can be concluded that climate change will affect crop growth and development, but the extent depends on many factors including crop species and water availability, i.e. the cropping system.

Table 4. *Helianthus annus* and *Cicer arientinum.* Effects of doubling CO_2 on changes (%) in crop criteria for rainfed chickpea and sunflower, predicted by GISS and GFDL

	Chickpea			Sunflower		
	Current	GISS	GFDL	Current	GISS	GFDL
Days to maturity	100	90.7	89.2	100	82.0	79.5
LAI	100	86.4	91.5	100	150	190.9
CGR	100	133.7	145.5	100	153.5	191.4
Biological yield	100	121.2	129.8	100	125.9	152.1
Grain yield	100	138.1	182.1	100	94.1	137.3
Harvest index	100	120.6	147.1	100	73.3	88.9

4. CONCLUSIONS

Climate change will not have a severe impact on yield of irrigated sunflower, but the negative effect for chickpea under irrigated conditions will be considerable.

For sunflower it can be concluded that: (1) sunflower under irrigation remains a viable crop in terms of yield under climate change; (2) impact of the change of annual temperature and precipitation on irrigated sunflower yield will not be a major problem because the shorter growing period will be compensated by higher CGR, (3) under rainfed conditions, in spite of higher CGR, harvestable yield of sunflower will be reduced due to reduction in harvest index.

For chickpea it can be concluded that: (1) irrigated chickpea crop will have a shorter growth period, reduced LAI and lower CGR from predicted climate change, leading to lower grain yield, (2) rainfed chickpea under doubling CO_2 concentration will experience a higher CGR and higher biological yield which together with increased harvest index results in yield advantages.

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