2011 International Conference on Environmental and Computer Science
IPCBEE vol.19(2011) © (2011) IACSIT Press, Singapore

Crop Water Consumption and Crop Yield Prediction under Climate Change Conditions at Northeast of Iran

Nasrin Sayari[1,*], Mohammad Bannayan[1], A. Farid[1], Amin Alizadeh[1] , Masoud Reza Hessami Kermani[2]

[1] Ferdowsi University of Mashhad, Faculty of Agriculture, P.O. Box 91775-1163 Mashhad, Iran
[2]Shahid Bahonar University of Kerman, Faculty of Engineering, P.O. Box 76169-133 Kerman, Iran

Abstract: Climate change can impact hydrological cycle through changes in precipitation pattern and amount, temperature, evapotranspiration, and run off. Such changes in climatic parameters can subsequently impact agricultural crop production. This study has been conducted with the aim to find relationships between crop yield and evapotranspiration with historical data (1984-2005) and predict crop yield under expected climate changes in the upcoming years in the northeast of Iran (kashafrood basin). Four major crops in this region were selected such as sugar beet, cotton, been, and chickpea. The future precipitation and temperature data are simulated by downscaling outputs of global climate model HadCM3 (A2 scenario) with ASD (Automated Statistical Downscaling) model. Projected temperature under A2 Scenario showed increasing trend for all three time periods. Projected annual precipitation increased by 4.64%, 5.41%, and 2.22% for (2010-2039), (2040-2069) and (2070-2099), respectively. To calculate the reference crop evapotranspiration, the Hargreaves-Samani (1985) equation was applied and validated for this region. The results showed a nonlinear relationship between crop yields and the seasonal evapotranspiration for all selected crops. Based on our results, seasonal evapotranspiration would increase under climate change scenarios for selected crops in study area. On the other hand, crop yield would increase for all crops except sugar beet. For 2070-2099 period, sugar beet yield would decrease in to base line period (1985-2005).

Keywords: climate change, crop yield, HadCM3 model, downscaling, Hargreaves-samani, Iran,

1. Introduction

In developing countries such as Iran, food security is an important issue due to low productivity of agricultural section. By increasing the temperature and decreasing the precipitation under future climate change and as indicated previously (Sayari et al., 2010), evapotranspiration would increase and it is expected that the crop yield decrease (Yu-Min Wang et al., 2008). Crop water use (evapotranspiration) is one of the most important variables for producing a profitable crop with optimum growth. Water stress has frequently impacted crop production in various locations across the country (Bannayan et al., 2008).Yield-seasonal ET relations have been widely used for management purposes in water deficient areas such as Iran as a guideline for irrigation. A number of studies have indicated a linear relationship between crop yield and the cumulative seasonal evapotranspiration. GCM models are able to project future values of climate parameters such as precipitation, temperature, wind speed and radiation which are required in modeling crops production under climate change. These models are not applicable in the local and regional scale because of their course resolution. Therefore higher spatial resolution can be obtained by downscaling GCM outputs (e.g., statistical and dynamical downscaling methods) (Olesen et al., 2007). Xiong et al. (2010) studying the climate change impacts on food production showed that total water demand increases by 20% and 18% for 2020s and 2040s, respectively in China. Irrigation water need show medium and large increase (B2 to A2 emission scenario.

[1] Corresponding author. Tel.: 09133973651
E-mail address: nasrin_sayari@yahoo.com.

Any relation between crop yield and climate in the past, present and future would be quite helpful for water, crop and farm management. The specific objectives of this study were, prediction of climatic parameters such as temperature and precipitation under A2 scenario and GCMs, compute the seasonal evapotranspiration by Hargreaves method for different time periods (2010-2039, 2040-2069, and 2070-2099 and finding the relationship between the crop yield and seasonal evapotranspiration and finally, evaluate these relationships with historical data set and using them to predict the crop yield for some crops in future research.

2. Materials and Methods

This study was performed for Kashafrood basin in the northeast of Iran (Fig. 1). This region is located between 35° 40' and 36° 3' north latitude and 58° 2'-60° 8' east longitude. The climatic pattern of this region, display a cold arid environment. The mean annual temperature is 13.6 ^{0}C and the total mean annual precipitation is 220 mm. The mean annual evapotranspiration is 735 mm.

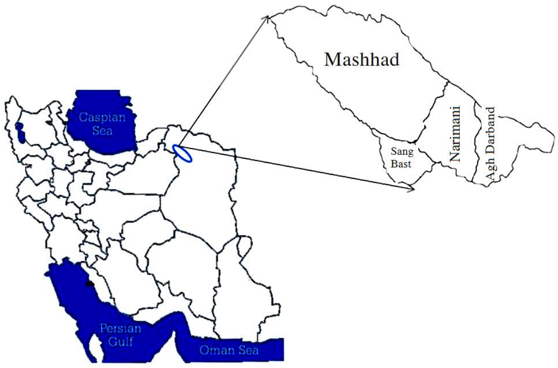


Fig. 1: The study area location (kashafrood basin in north-east of Iran)

To evaluate the impact of climate change (global warming) on temperature, precipitation and evapotranspiration, and their effects on crop yield under the global warming conditions, the projection of changes of climatic parameters is prerequisite. The sugar beet, cotton, wheat, barley, cereals, sunflower, vegetables, corn and fruit tree are the crops, which were grown in this basin. Four major crops in this region were selected such as sugar beet, cotton, been, and chickpea. Long term annual average yield are about 31 t ha^{--1} for sugar beet, 2.5 t ha^{-1} for cotton, 1.25 t ha^{-1} for chickpea and 1.0 t ha^{-1} for bean.

The daily observed historical values of maximum, minimum, daily average temperature (^{0}C), and precipitation (mm) were obtained for period of 1961-2005 from Mashhad station, which was located in the Kashafrood basin. To calculate the reference crop evapotranspiration, the Hargreaves-Samani (1985) equation was applied and validated for this region. This equation was:

$$ET_o = 0.0135(KT)R_a(TD)^{0.5}(T + 17.8) \quad (3$$

$$KT = 0.00185(TD)^2 - 0.0433(TD) + 0.4023 \quad (4$$

$$TD = T_{max} - T_{min} \quad (5$$

Where, ET_o is the reference crop evapotranspiration (alfalfa) (mm/day); T is the monthly average temperature (°C); T_{max} and T_{min} are monthly maximum and minimum temperature (°C), respectively. R_a is the water equivalent of the extraterrestrial radiation (MJ/day), which was calculated based on the latitude and also the specific month in study area. KT is an empirical constant that was calculated from the equation 3. Etc (crop evapotranspiration) was calculated from the product of Et_o and crop coefficient (Kc), where the effects of various weather conditions were put into the Etc and crop characteristics:

$$Etc = ET_o \times Kc \quad (6$$

Crop coefficient and Length of growth stages for the selected crops were derived based on FAO56 and corrected according to crop growth stages and the length of the crop growth. To project the future crop yield, HadCM3 model (Gordon et al., 2000) was used under A2 scenario (the rapid warming) for three time periods (2010-2039, 2040-2069, and 2070-2099). An automated regression based statistical downscaling model (ASD, Hessami et al, 2008) was used for downscaling output of HadCM3 model in this research.

3. Results

3.1. Projecting climate parameters

Calibration and validation of ASD model for monthly precipitation, maximum temperature, and minimum temperature were performed independently using daily data from 1961 to 1990. The maximum and minimum temperature data were projected by HadCM3 model under A2 scenario, matched quite well with observed data. Precipitation data projected by HadCM3 model under A2 scenario, also matched well with observed data Results indicates the range of increase of maximum temperature under A2 scenario (2070-2099) which for spring is 5.4 ^oC to 5.8 ^oC, for summer time is 5.1 ^oC to 5 ^oC, for fall would be 4.4 ^oC to 5.8 ^oC and for winter projected 5.6 ^oC to 4 ^oC. Results also, shows that maximum value of minimum temperature under A2 scenario (2070-2099) were 2 ^oC to 1.7 ^oC, 1.8 ^oC to 4.1^oC, 3.3 ^oC to 1.8^oC and 1.8 ^oC to 1.1^oC, which would occur in spring, summer, fall and winter seasons, respectively.

3.2. Calculating crop evapotranspiration

The climatic parameters used to calculate the ETo were maximum temperature, minimum temperature and extraterrestrial radiation. Fig. 2 shows that during 1985-2005, crop seasonal evapotranspiration has decreased at a rate of 13.4%, 14.6%, 19.8%, 19.4% and 19.9% for sugar beet, cotton, bean, and chick pea, respectively. Figure 3 and 4 showed yield and seasonal evapotranspiration trend in 1984-2005 periods, respectively.

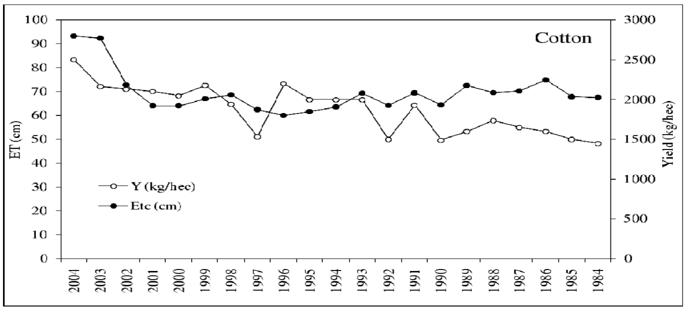
3.3. Relationship between crop yield and seasonal crop evapotranspiration

The projected climatic data in this study was used for estimating the yields of selected crops under climate change conditions. Relationships between crop yields and seasonal evapotranspiration are shown in Fig. 3. These equations were obtained based on historical data for the period 1984 to 2005. Ten years (1989-2000) for calibration and six years (2000-2005) for validation of equations were deployed.

The measured Etpfs are curvilinear and are computed using a second order poly nominal. For example, the measured Etpf for sugar beet is:

$$y = 5.696x^2 - 2221.7x + 180911, \quad R^2=0.6 \qquad (10$$

Where, y is the sugar beet yield (kg ha^{-1}) and x is the seasonal evapotranspiration (cm). Figure 4 these relationships for selected crops in study area. Simulated vs. measured crops yield is shown in Fig. 4.



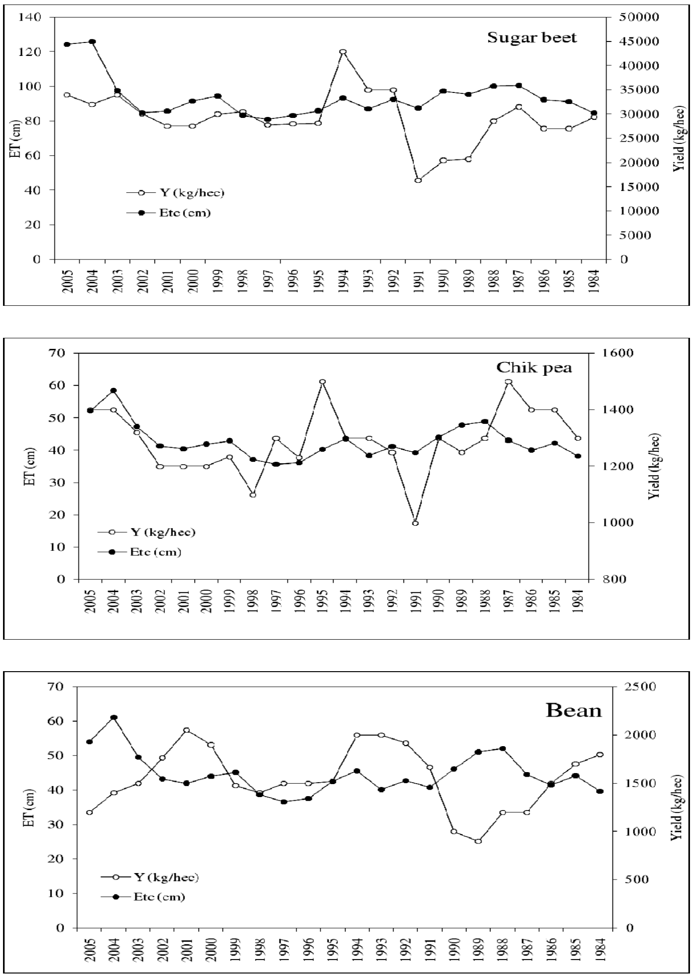
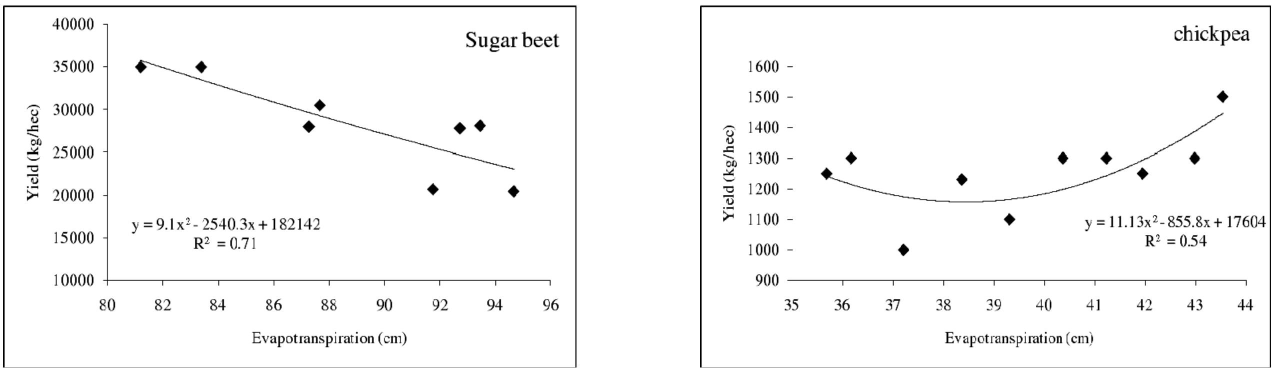


Fig. 2: Yield and evapotranspiration trend selected crops for 1984-2005 periods at study area

In all cases, seasonal evapotranspiration will increase because of higher projected temperature under climate change conditions. Simulated sugar beet production were 9.5, 4.81 and 9.8 t ha^{-1} for 2010-2039, 2040-2069 and 2070-2099 period, respectively. For similar periods, simulated yields for cotton, been, and chickpea were 7.93, 9. 1.1 and 0.88, 1, 2.6 and 5.17, 14.31. 43.3 t ha^{-1}, respectively. The seasonal crop evapotranspiration of sugar beet would increase by 37.4%, 58.7% and 93% for the three periods (2010-2039, 2040-2069 and 2070-2099), respect to 2005. These rates of increasing trends for cotton were 40.6%, 62% and 96%, for been, 38%, 66% and 100%, for chick pea, 39%, 66% and 100% for three periods of prediction, respectively. Sugar beet, cotton, and chick pea production in 2010-2039 period would have been roughly 170%, 200%, 190% higher since 2004, respectively. Bean yield for this period would decrease compare to base year by 26%. For 2040-2069 time period, bean production would decrease by 16% but other crops yield would increase comparing to 2004. Sugar beet yield would decrease compared to 2010-2039 period. In 2070-2099, bean production would increase by 100%.



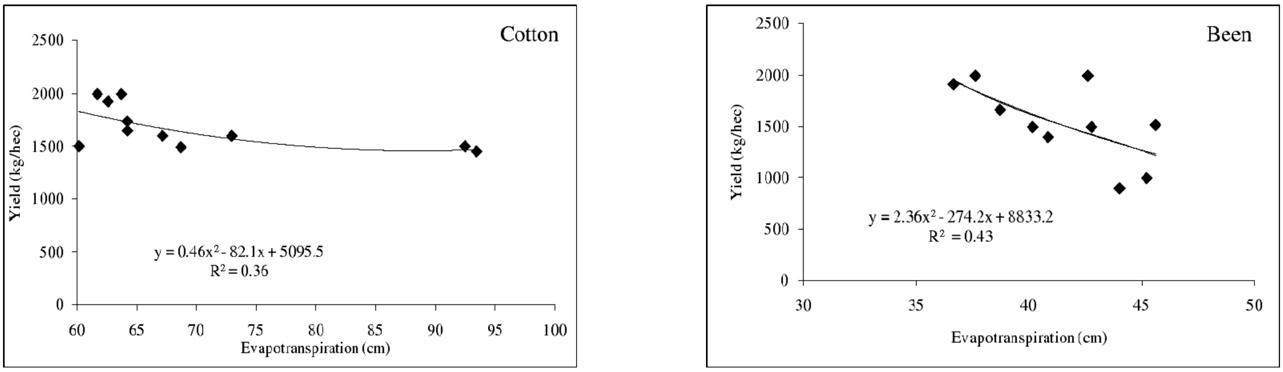


Fig. 3: Relationship between evapotranspiration (cm) and yield crop (kg/hec)

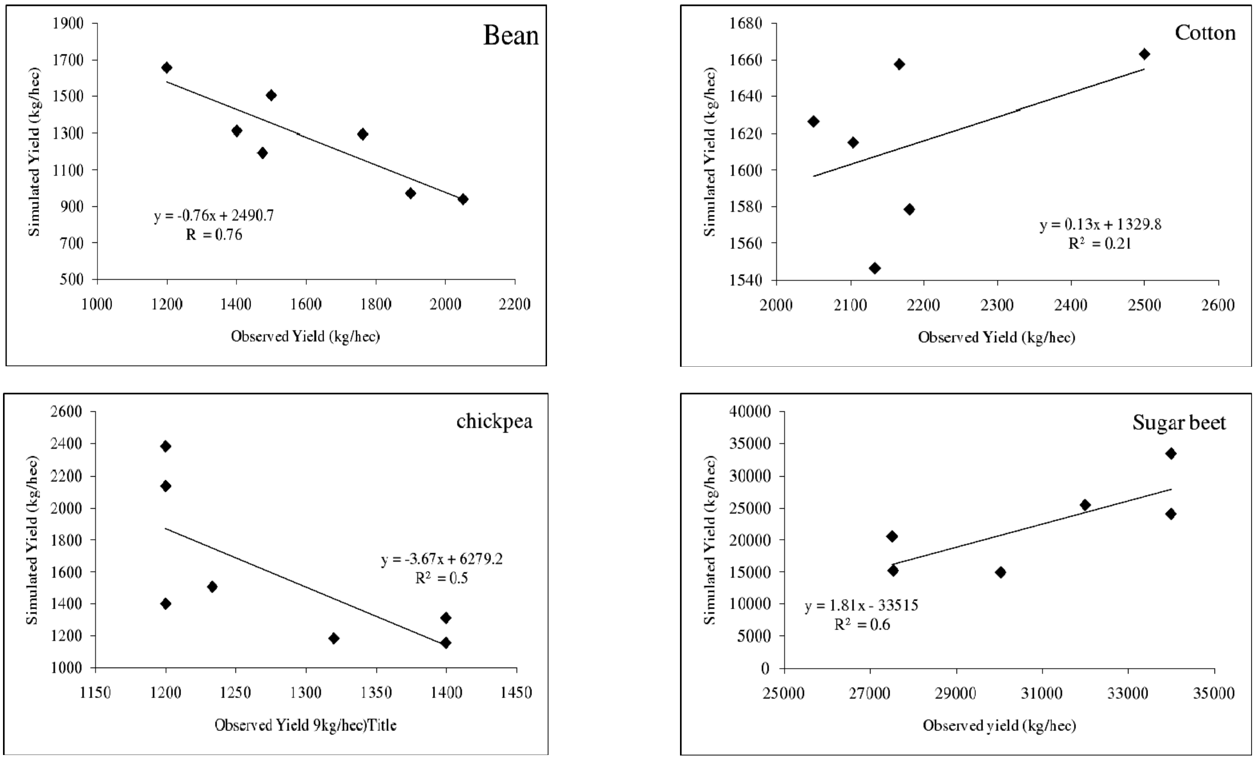


Fig. 4: validation relationship between crop yield and seasonal evapotranspiration

4. References

[1] Yu-Min Wang; S. Traore; T. Kerh.. Computing and modeling for crop yield in Burkina Faso based on climatic data information. WSEAS Transaction on Information Science & Applications. 2008, 5(5): 832-842.

[2] M. Bannayan, F. Nadjafi, M. Azizi, L. Tabrizi and M. Rastgoo. 2008. Yield and seed quality of Plantago ovata and Nigella sativa under different irrigation treatments. Journal of Industrial Crops and Products. 27, 11-16.

[3] J. .I Stewart, R. M. Hagan, W. O. Pruitt, R. J Hanks, J. P Rilley, R. E Danilson, W. T Franklin and E. B Jackson.. Optimizing crop production through control of water and salinity levels. Utah water Res. Lab. PRWG. 1977, 151-1.Septamber.

[4] J. E. Olesen, T. R. Carter, C. H. Díaz-Ambrona, S. Fronzek ,T. Heidmann , T. Hickler , T. Holt , M. I. Minguez , P. Morales ,J. P. Palutikof, M. Quemada , M. Ruiz-Ramos , G. H. Rubæk, F. Sau , B. Smith and M. T. Sykes. Uncertainties in projected impacts of climate change on European agriculture and terrestrial ecosystems based on scenarios from regional climate models. Climate Change. 2007, 81: 123-143.

[5] W. Xiong, L. Holman, L. Erda, D. Conway, J. Jiang, Y. Xu and Y. Li. Climate change, water availability and future cereal production in China. Agriculture, Ecosystems and Environment. 2010, 135: 58–69.

[6] G. H. Hargreaves and Z. A. Samani. Reference crop evapotranspiration from temperature. Applied Engineering in Agriculture. 1985, 1(2): 96-99.

[7] C. Gordon, C. Cooper C. A. Seinor, H. Banks, J. M. Gregory, T. G. Johns, J. F. B. Mitchell and R. A. Wood. The simulation of SST, Seas ice extents and ocean heat transports in a version of the Hadley Center coupled model without flux adjustment. Climate Dynamics. 2000, 16: 147-168.

[8] M. Hessami, P. Gachon., T. B. M. J. Ouarda and A, St-Hilaire. Automated regression-based Statistical Downscaling tool, Environmental Modeling and Software. 2008, 23: 813-834.

[9] N. Chattopadhyay and M. Hulme. Evaporation and potential evapotranspiration in India under conditions of recent and future climatic change. Agricultural and Forest Meteorology. 1997, 87 (1): 55–74.