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Simulation of Rainfed Wheat Yield Response to Climatic Fluctuations Using Model (Case Study: Shiraz Region in Southern of Iran)

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ABSTRACT *: The rainfed agriculture is normally the first sector to be economically affected by drought. To monitor drought, indices can serve as important tools, establishing an accurate connection among many of climatic parameters. To facilitate farmers' use of complementary irrigation for a special type of crop in a particular region, one can make use of an hydrological model, while considering the yield of the crop against climatic fluctuations. The purpose of the present study is to monitor climatic fluctuations by RDI index, determine the degree of boundary conditions for climatic dryness, normal, and humidity, and simulate the crop yield of response in rainfed agriculture use of the model in Shiraz, south of Iran. The results showed in most of the cases, the increase or decrease in the crop yield corresponds to climatic fluctuations. The results reveal that rainfed wheat is affected by climatic fluctuations in the region under study. The values of the evaluation criteria (Coefficient of the Residual Mass (C_{RM}), Relative Root Mean Square Error (RRMSE), and Mean Absolute Error (MAE) suggest the model's capacity for estimating the rainfed yield of wheat in the region. Thus, the AquaCrop model can prove to be helpful for investigating the effects of climatic fluctuations and formulating strategies for wheat yield. So, the model can be used as a subsidiary decision-making tool to simulate the effects of climatic fluctuations on crop product.*

Keywords – *Rainfed Wheat, Climate Fluctuation, AquaCrop*

I. INTRODUCTION

The rainfed agriculture is normally the first sector to be economically affected by drought. If a short-term period of drought strikes during plants' developmental stages, it can bring about intensely critical consequences. Monitoring systems are specifically important in formulating plans for tackling and managing drought. To monitor drought, indices can serve as important tools, establishing an accurate connection among many of climatic parameters. Since indices give important information useful for planning designing and management application of water resources related to various users and the environment numerous indices have been proposed and used. This issue can be reflected in comparative studies on indices (Richard and Heim, 2002; Hayes, 2004; Tsakiris and Vangelis, 2005).

Recently, a new index for drought assessment and monitoring is presented called Reconnaissance Drought Index (RDI). RDI is calculated based on precipitation and potential evapotranspiration. This index has been used in various studies to monitor drought and climatic fluctuations (Asadi Zarch, 2011; Khalili et al., 2011; Tigkas, 2008; Tsakiris et al., 2007). To facilitate farmers' use of complementary irrigation for a special type of crop in a particular region, one can make use of an hydrological model, while considering the yield of the crop against climatic fluctuations. Under such circumstances, managerial guidelines can be developed with due consideration of the results arising from the monitoring of climatic fluctuations and the simulation of the crop yield. These guidelines are regulated by taking into account the climatic specifications of the region, its soil type, and managerial conditions. Applying managerial plans through an exclusive reliance on farm research can be demanding and time-consuming. Using plant growth simulation models, one can investigate the effects of various managerial and environmental factors, as well as plant resistance against the tensions caused by such clime fluctuations as drought. In the past decades, a considerable number of argo-hydrological models have been proposed to simulate plant growth as well as the motion of water and salt through soil. Viewed from a general perspective, such models are used to analyze the results of experimental and agricultural researches (Steduto et al., 2009). A plant model, armed with a set of dependent environmental variables and genetic specifications, can help predict the growth, development, and yield of a plant (Monteith, 1996). Other plant models can be utilized as decision-making tools for system management (Steduto et al., 2009). To set an optimal time-table in conditions of water shortage, the plan developer will need a sound understanding of plant response to water stress, while this whole process can be carried out according to plant growth simulation models (Farahani et al., 2009).

The AquaCrop model can be used to simulate crop growth against long series of past climatic data. This model can simulate the yield of many types of crops is response to the water consumed from rainfall, complementary irrigation, and conditions of scarcity or affluence of water. Plant models can also be utilized as decision-making instruments facilitating system management (Steduto et al., 2009). The AquaCrop model is one of the recently developed plant models which has been evaluated in various regions worldwide, while it has yielded more desired results compared to field measurements. The concepts, regulations or synthesized methods of simulation in the AquaCrop model were proposed by Steduto et al. (2009). Raes et al (2009a), too, have described the major algorithms used in the model software and application. Heng et al. (2009) in a study calibrated the functioning of the AquaCrop model for corn under low-water conditions. The results showed the model was applied in treatments without water stress and moderately stressing conditions. Using the the AquaCrop model, Geerts et al. (2009) simulated the yield response of onion to water. The results indicated that under thorough irrigation water exploitation had declined 9 % compared to rainfed or low-water conditions. The model, too, was used in other researches to optimize water use management, bringing about acceptable results (Araya et al., 2010b; Araya et al., 2010a; Saadati et al., 2011; Todorovic et al., 2009). The purpose of the present study is to monitor climatic fluctuations by RDI index, determine the degree of boundary conditions for climatic dryness, normal, and humidity, and simulate the crop yield of response in rainfed agriculture use of the model in Shiraz, south of Iran.

II. METHOD

The Reconnaissance Drought Index (RDI)

The Reconnaissance Drought Index (RDI) is calculated in three stages: Initial value of RDI (a_0), normalized RDI (RDIn) and standardized RDI (RDIst). Initial value may be calculated for each month, seasons (3-month, 4-month, etc.) or hydrological year. The a_0 is calculated by using the following equation (Tsakiris et al., 2007; Asadi Zarch et al., 2011)

$$a_0^{(i)} = \frac{\sum_{j=1}^{12} P_{ij}}{\sum_{j=1}^{12} PET_{ij}}, i = 1(1)N \ and \ j = 1(1)12 \qquad (1)$$

Where P_{ij} and PET_{ij} are the precipitation and potential evapotranspiration of the jth month of the i^{th} hydrological year. Hydrological year is starting from October in Iran. N is the total number of years of the available data.

A second step, the Normalized RDI (RDI_n) is computed using the following equation for each year, in which it is evident that the parameter a_0 is the arithmetic mean of a_0 values (Tsakiris et al., 2007; Asadi Zarch et al., 2011).

$$RDI_n^{(i)} = \frac{a_0^{(i)}}{\bar{a}} - 1 \qquad (2)$$

The third step, the Standardized RDI (RDI_s), is computed following a similar procedure to the one that is used for the calculation of the SPI: The equation for the Standardized RDI is:

$$RDI_{st(k)}^{(i)} = \frac{y_k^{(i)} - \bar{y}_k}{\hat{\sigma}_{yk}} \qquad (3)$$

Where y_k is the ln(a_0 ; $\bar{y}_k$) is its arithmetic mean of y_k , and $\hat{\sigma}_{yk}$ is its standard deviation.

Description of the model

The AquaCrop model explores the factors of soil, plant, and atmosphere. Atmosphere factors include rainfall, temperature, evapotranspiration, and Carbon dioxide concentration. Plant factors include phonological specifications, vegetation root depth, dry matter, and yield. Agricultural management, too, involves irrigation, fertility, and agricultural methods (Raes et al., 2009a; Steduto et al., 2009). The model is derived from Doorenbos and Kassam's (1979) equation through separating (a) actual evapotranspiration (ET_a), evaporation from soil surface (E_s), crop transpiration; (b) final yield of the crop (Y) to dry matter (B) and harvest index (HI) (Equation 4).

$$\left(\frac{Y_x - Y_a}{Y_x}\right) = k_y\left(\frac{ET_x - ET_a}{ET_x}\right) \qquad (4)$$

which, Y_x is represents the maximum of crop yield, $Y_{a:}$ the actual crop yield, ET_x: the maximum of evapotranspiration, ET_a: actual evapotranspiration, and K_y: factor between reduce the relative and relative decline in evapotranspiration.

The Study Area

Shiraz City in Fars Province in southern part of Iran, is located at 53 37 E longitude and 29 57 N latitude with the area of 10434 square kilometers. The mean annual precipitation 330 mm and mean annual temperature for the study area about 18 °C (I.R. of Iran Meteorological Org.). The geographical location of the study region is shown in Figure 1.

To simulate crop response to climatic fluctuations according to the information of boundary conditions of climatic dryness, normal, and wetness used the RDI index for drought monitoring. The input files of _mdel are include meteorological information, potential evapotranspiration calculated through Penman–Monteith method, soil specifications, and crop information. Thus, crop growth simulation was performed individually for 12 years.

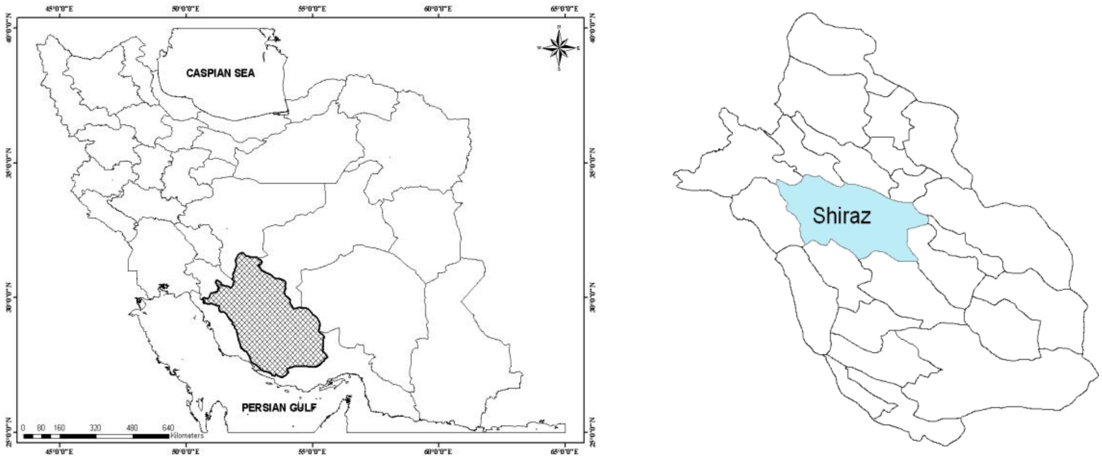

Fig. 1.Regional map of Iran, Fars Province and Shiraz City

Model Calibration

The AquaCrop model is comprehensive model which can process a wide range of agricultural crops including forage, vegetables, grains, fruits, and oil and glandular products. When the model is appropriately calibrated for a particular crop, it can serve as an effective tool for water management strategies to enhance the yield and store water. To calibrate crop parameters, yield response observed data was used for 3 crop year in the region of Shiraz.

Model

The model was evaluated through a comparison of the simulated yield and observed data. To do this, Coefficient of the Residual Mass (C_{RM}), Relative Root Mean Square Error (RRMSE), and Mean Absolute Error (MAE) were used.

$$C_{RM} = \frac{[\sum_{i=1}^{n} o_i - \sum_{i=1}^{n} s_i]}{\sum_{i=1}^{n} o_i} \qquad (5)$$

$$RRMSE = [1/n \sum_{i=1}^{n} (S_i - O_i)^2]^{0.5} \left(\frac{100}{MO}\right) \qquad (6)$$

$$MAE = \frac{1}{n}\left(\sum_{i=1}^{n} |O_i - S_i|\right) \quad (7)$$

In the above equations, S_i and O_i represent simulated and observed values respectively, MO: mean of observed values and N: number of observations. The more the values of C_{RM}, RRMSE, and MAE approach zero, the better the simulation performed by the model.

III. RESULTS

The relation of intensity and duration of drought, as the time series of RDI in different time scales, are presented in the Shiraz station (Figure 2). As far as frequency is concerned, arid and wet periods were equal during the statistical period. In 1983, 1985, 1987, 1993, 1994, 1999-2000, 2002-2003, and 2007-2008, had occurred moderate and severity drought. Over the total statistical period under study, the droughts occurring in 2007 and 2009 showed the maximum intensity and duration. After them, the most intense droughts happened in 1999 and 2000.

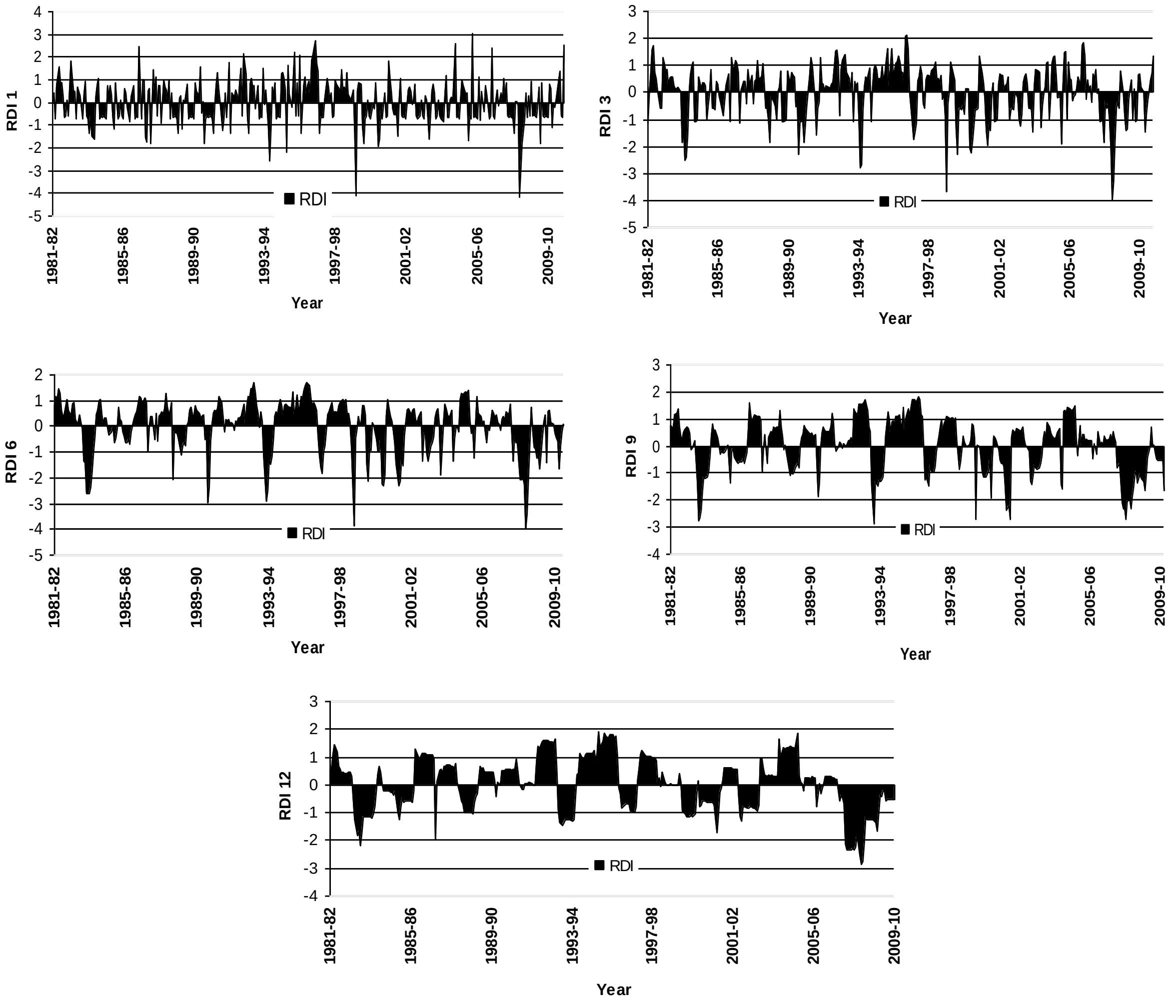

Fig.2. RDI series of different monthly time scales at Shiraz station

Annual precipitation during the study period ranged from 119 to 512 mm with an average of 312 mm. The periodical fluctuations in annual rainfall shows that the minimum percentage of rainfall refers to the last year investigated in the study (Figure 3).

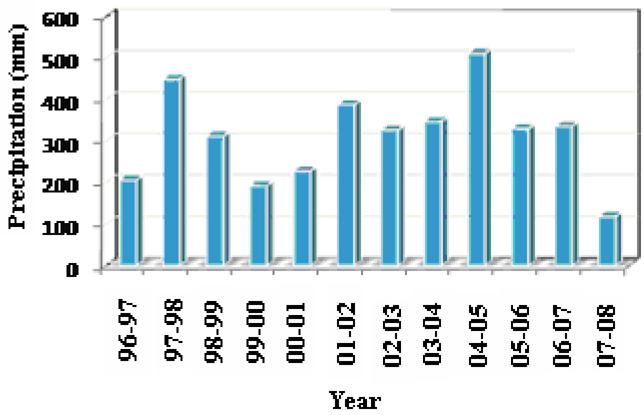

Fig. 3. Precipitation changes over the studied in Shiraz region

Simulation

The observed yield values throughout the years under study in the region of Shiraz showed various values ranging from 157 to 1390 kg per hectare. In the region of Shiraz, the simulation of yield processed by the model showed overestimation in 5 cases, while it was underestimated in 7 cases (Figure 4). Considering the temporal importance of rainfall and its distribution through the growth period of rainfed crops, the yield did not follow the total rainfall changes for each year. Of course, in most of the cases, the increase or decrease in the crop yield corresponds to climatic fluctuations. For instance, the degree of rainfed wheat yield in Shiraz covered 1102 kg per hectare in 1997-1998, 756 kg per hectare in 1996-1997, and 175 kg per hectare in 2007-2008. The results of a comparison of the wet and dry years monitored by RDI (Figure 2) show that in 1997-1998, a relatively intense wet period happened. In 1996-1997 after a wet period drought stroke, whereas in 2007-2008 intense and prolonged droughts occurred. The results reveal that rainfed wheat is affected by climatic fluctuations in the region under study. Therefore, if the model brings about satisfactory results in simulating the yield of wheat, it can be used as a subsidiary decision-making tool to simulate the effects of climatic fluctuations on crop product.

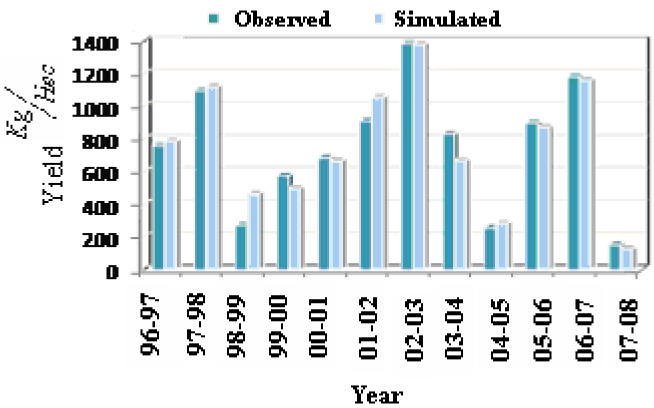

Fig. 4. simulated and observed in Shiraz region

Model evaluation

Figure 5 shows the values simulated by the model compared with those observed. As can be seen, the correlation line between the simulated and observed values has a gradient of 1.017 and correlation coefficient 0.91, both of which reveal the vicinity of the values to 1.1 and the acceptable estimation of the model. Also, the criteria for evaluating the model in simulating the yield are presented in Table 1. The values of the evaluation criteria suggest the model's capacity for estimating the rainfed yield of wheat in the region. Thus, the AquaCrop model can prove to be helpful for investigating the effects of climatic fluctuations and formulating strategies for wheat yield.

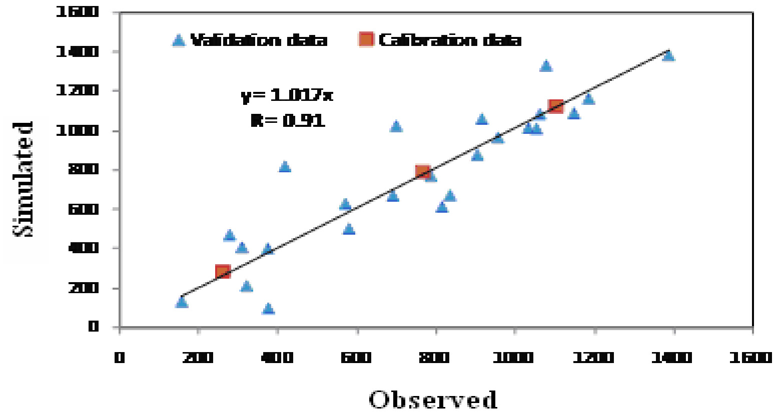

Fig. 5. Comparing the ~~values~~ simulated values by the model with those observed

Table 1. Model evaluation criteria for simulating the yield

C_{RM}	RRMSE	MAE	Region
-0.009	11.8	63	Shiraz

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