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Irrigation scheduling and winter wheat grain yield estimation under precipitation uncertainty – A case study in Badjgah area (Fars Province, Iran)

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ABSTRACT-Addressing deficit irrigation scheduling (DIS) for strategic crop production (especially wheat) under precipitation uncertainty is a priority for irrigation scheduling in drought conditions. This research investigated the precipitation uncertainty by enacting optimistic and pessimistic scenarios for the next 20 years by considering the statistical record of climate in Badjgah area. DIS was conducted in spring in two ways: (1) reducing the quantity of irrigation water at each irrigation event; (2) reducing the number of full irrigation events. Results indicated that, owing to the effect of precipitation increase on yield enhancement, grain yield in the optimistic scenario was on average 7% higher than those obtained in the pessimistic scenario. Furthermore, grain yields obtained via the second method of DIS was on average 8% higher than those obtained by the first method of DIS and further by increasing the water reduction fraction (WRF) to 0.6, this difference reached about 20% due to the effect of early spring irrigation events on yield enhancement. At low irrigation application efficiency (Ea), the difference between DIS methods was greater at higher WRF. Net income obtained through the second method of DIS was on average 70% higher than those obtained via the first method of irrigation for all conditions due to decreasing the number of irrigation events and thus decreasing the production costs. Eventually, results indicated that in both scenarios of the precipitation uncertainty in drought conditions, the second method of DIS, i. e., application of available water based on growth stage, was more fruitful.

INTRODUCTION

Drought occurs as a result of severe climate fluctuation that is a very important issue in arid and semi-arid regions. This phenomenon affects farmer's income seriously. In this regard, water resources management especially in agricultural sector is extremely important. The development of technologies to reduce irrigation water demand and improve water saving is important for the sustainability of water use in agriculture with climate uncertainty (Popova and Pereira, 2008). An appropriate irrigation scheduling plays an important role in saving water, having a higher irrigation performance, and controlling water percolation, resulting from excess water use in irrigation (Smith et al., 1996; Pereira et al., 2002; Pereira et al., 2009). Proper water management at crop/farm level, i.e., when and how much to irrigate, also plays an important role. In drought years, farmers may have to adopt deficit irrigation to cope with the limited water availability. Deficit irrigation consists of deliberately applying irrigation depths smaller than those required to satisfy the crop water requirements (CWR) at certain periods in the growing season. Therefore, it affects evapotranspiration and yields, but keeps a positive return from the irrigated crop (English and Raja, 1996; Sepaskhah and Ghahraman, 2004; Rodrigues and Pereira, 2009).

Water balance models that are calibrated properly are practical, efficient and acceptable precision tools for scheduling irrigation and estimating yield. By knowing the effect of evapotranspiration and soil water variability on yield, we can optimize the design and management of irrigation to improve the economic and agronomic performance of irrigation. Efficient management of irrigation is necessary for wheat crop under precipitation uncertainty. Accurate modeling of crop water requirements can improve irrigation management. Such models can be used to determine the optimal water saving and environmentally oriented irrigation practices under different precipitation scenarios in agriculture, especially at drought conditions (Pereira et al., 1995; Sepaskhah and Akbari, 2005; Cancela et al., 2006; Sepaskhah et al., 2006; Popova and Pereira, 2008; Geerts et al., 2010; Misra et al., 2010; Sepakhah and Tafteh, 2012). Using a wheat growth simulation model calibrated for the study area, we can forecast the wheat yield at the time of planting under different irrigation management programs (Ziaei and Sepaskhah, 2003). Crop growth in arid and semi-arid regions is closely related to availability of irrigation water for irrigated wheat and it is related to precipitation for rain-fed wheat. Therefore, simulation of the effects of water on wheat yield can result in irrigation scheduling and it can determine the effect of low or high precipitation depth on wheat yield (Ziaei and Sepaskhah, 2003).

MEDIWY model is based on physiological findings on wheat plant production in recent decades. The model employs the equations for minimizing the need for calibration and fitting that are obtained and verified by other studies. The MEDIWY model was first presented by Cordery and Graham (1989). Then, this model was modified as a new computer program by Ziaei and Sepaskhah (2003) according to the flowcharts introduced by Cordery and Graham. Some of the water balance equations in the model were updated and a new equation was used to define the relationship between leaf area and total dry biomass. Then, this model was re-calibrated for estimation of rain-fed and irrigated winter wheat cultivar Adle yields, by Ziaei and Sepaskhah (2003), in Bdjgah area, Fars province, Islamic Republic of Iran. For confronting drought conditions in the study area, this model should be calibrated for the new cultivars in the study region for better irrigation scheduling management and thus saving water. The objectives of this research were to calibrate and validate the MEDIWY model for winter wheat cultivar Shiraz (*Triticum aestivum* L. cv. Shiraz) in Badjgah area. Then, it was used to schedule deficit irrigation for winter wheat under precipitation uncertainty.

MATERIALS AND METHODS

Study Area

This research was carried out in Badjgah district with semi-arid climate, located at 16 km north of Shiraz, I. R. of Iran (longitude of 52.46° E, latitude of 29.50° N and 1810 m elevation). The mean monthly temperature, relative humidity and rainfall of the study area are presented in Table 1.

Table 1. Mean monthly climatic data (Badjgah meteorological station)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean temperature,˚C	3.6	5.2	8.9	12.9	17.6	21.7	24.0	22.9	19.3	14.0	8.9	5.0
Mean relative humidity, %	59.5	56.5	53.8	51.8	47.0	41.8	40.8	41.7	44.1	48.8	54.1	58.9
Precipitation, mm/month	86.0	71.3	54.5	33.2	8.7	0.6	0.3	0.3	0.8	8.9	42.1	83.4

Simulation Model (Calibration and Validation)

The MEDIWY model consists of water balance and crop yield submodels. Water balance submodel predicts the available soil water during the growing season and crop yield submodel provides estimation of yield based on the predicted available soil water (Ziaei and Sepaskhah, 2003). The model consists of a main program and nine subroutines. The subroutines are: constant values, water balance, sowing date determination, evaporation calculation, phonological clock, evapotranspiration calculation, stress determination, crop yield estimation and statistical parameters. More information about the model is given by Ziaei and Sepaskhah (2003).

The data set used for calibration and validation of the model include volumetric soil water content at planting date and at field capacity; permanent wilting point at different layers of winter wheat root zone; the date and amount of applied irrigation water during winter wheat growing season, and the obtained dry matter and grain yield in different irrigation treatments consisting of 100%, 75% and 50% of full irrigation requirement. The data provided by Fateh (2009) were obtained from the experiments conducted at the Badjgah Agricultural Experiment Station for two consecutive years (2007-2008 and 2008-2009). Planting and harvesting dates were 31 October and 3 July, respectively. The second year data were used for calibration and the first year data for validation. In this study, the seed density of 240 kg ha^{-1} was selected because it, according to Fateh (2009), would lead to the highest grain yield. The soil type at the site was silty clay loam (35% clay, 55% silt and 10% sand for soil depth of 0.0-0.1 m and 34% clay, 52% silt and 14% sand for soil depth of 0.10-1.10 m). The volumetric soil water contents at planting date were 0.116 cm^3 cm^{-3} at soil depth of 0.0-0.10 m and 0.14 cm^3 cm^{-3} at soil depth of 0.10-1.10 m and for field capacity and permanent wilting point were 0.3 and 0.11 cm^3 cm^{-3} at soil depth of 0.0-0.10 m, respectively and 0.33 and 0.16 cm^3 cm^{-3} at soil depth of 0.10-1.10 m, respectively. The depth to the water table was about 26 m.

Scenarios for Precipitation Uncertainty

Investigating the precipitation amount during winter wheat growing season (October-June) during the past three decades (1980-2010) in the study area showed a decreasing trend (Fig. 1). The slope of this trend in the past 25 years (1985-2010) was significant ($p<0.05$). This fact allowed establishing scenarios for possible variation of precipitation during the winter wheat growing season. According to Fig. 1, in 1985-2010 in Badjgah area, there was a decreasing trend for precipitation. The annual precipitation reduction was 190 mm during the winter wheat growing season. In this research, uncertainty in precipitation that described the precipitation uncertainty was considered through building a pessimistic and an optimistic scenario. The pessimistic scenario was based upon the assumption that, like the previous years, the trend of annual precipitation decrease would continue for the next 20 years (2010-2030). The optimistic scenario assumed a reversing trend for the period 2010-2030. These scenarios were not resulted from precipitation forecasting; rather, they were just built to assess possible consequences of precipitation variations on the winter wheat irrigation demand and to check how the considered irrigation scheduling alternatives would behave if precipitation during winter wheat growing season did or did not decrease.

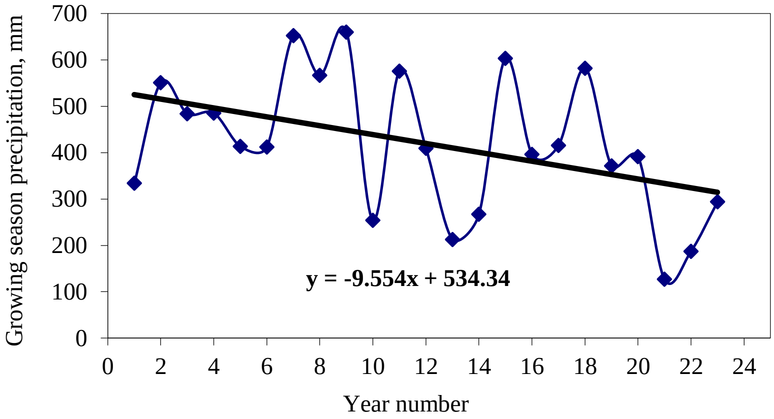

Fig. 1. Trend of annual precipitation variations in winter wheat crop growing season over last 25 years (1985-2010) in Badjgah area

Simulation of Irrigation Scheduling Scenarios under Precipitation Uncertainty

In each scenarios of precipitation uncertainty, the average quantity of precipitation for next 20 years (2010-2030) was calculated. Then, among the preceding 25 years (1985-2010), the year whose precipitation was the same as the average amount of precipitation for the next 20 years was selected. By using the weather parameters of the selected year, the irrigation scheduling was determined. For full irrigation scheduling and irrigation application efficiency (E_a) of 100%, the quantity of irrigation was considered equal to crop potential evapotranspiration, ET_c and irrigation water was applied when the soil readily available water was used. ET_c was calculated using FAO dual crop coefficient method (Allen et al., 1998). This procedure was conducted on a daily basis and it was intended for applications using computers. The dual crop coefficient approach was followed when improved estimates for K_c, such as, irrigation schedule for individual fields on a daily basis, were needed. (Allen et al., 1998).Solution consisted of splitting K_c into two separate coefficients, one for crop transpiration, i.e., the basal crop coefficient (K_{cb}), and another for soil evaporation (K_e) (Allen et al., 1998):

$$ET_c = (K_{cb} + K_e)ET_o \quad (1)$$

where ET_o was the reference crop evapotranspiration, in mm d^{-1} and was calculated by using the FAO Penman-Monteith method that had been modified for the study region by Razzaghi and Sepaskhah (2012). In drought conditions, enough water was not available to meet crop water requirement. Therefore, deficit irrigation scheduling (DIS) was used to calculate the initial date and amount of full irrigation events and then two methods of DIS were applied as follows:

Method 1: Relative applied water (1-WRF) i. e., 0.8, 0.6, 0.4 and 0.2was multiplied by the quantity of each full irrigation event calculated for the spring season.

Method 2: Relative applied water (1-WRF) was multiplied by the total number of full irrigation events obtained for the spring season. However, full irrigation was applied at each event of reduced number of irrigation events.

In this study, different application efficiencies i. e. 100%, 90%, 80%, 70% and 60% were used.

Net Income

Net income (NI= gross income-production cost) earned per unit area (hectare) was determined by using Eq. (2) as production cost:

$$C = a_1 + b_1W \quad (2)$$

where C is the total production cost, in Rls ha^{-1}, W is the water used, in m^3 ha^{-1} and "a_1" and "b_1" are constants.

Equation (2) expresses the relation between consumed water and production cost. In this equation, the production cost is divided into two parts: fixed and variable costs. Fixed cost (a_1) includes land rent, cultivation operation cost and irrigation system equipments and designing costs. Variable cost (b_1W) includes applied water, labor and yield transportation costs. In this study, for calculating the cost of unit cubic meter of water for agricultural use in the study region, Eq. (3) was used (Abdollahi Ezzatabadi, 1996):

$$Y_t = 8.39 + 0.455(D) \quad (3)$$

where Y_t is the total production cost of unit cubic meter of water, Rls and D is the well depth for groundwater discharge, m. Equation (3) has been obtained by considering the total cost and average annual volume of water obtained from groundwater through pumping because in addition to precipitation, groundwater is the only water supply for agricultural use in the Badjgah area.

For calculating NI, the production cost and gross income (the income from the grain yield) were calculated per unit area (hectare). Then, the production cost was deduced from gross income. The fixed cost of production for surface irrigation system was $7.76*10^6$Rls ha^{-1}. The labor and yield transportation costs were considered equal to 120000 Rls per day (8h) and 60 Rls kg^{-1} according to the local information.

Model Calibration

Parts of the model that were modified are as follows:

a) Modification in water balance submodel (WATLAB) WATLAB was developed for appropriate estimation of important parameters, such as partitioning of available energy between evaporation and transpiration. The potential evaporation and transpiration were dependent on pan evaporation and leaf area index (LAI). LAI was calculated as the product of leaf area ratio (LAR, ha leaf kg^{-1}) and above ground green biomass (GDM, kg ha^{-1}).

$$Epot = Epan exp(-0.55\ LAI) \quad (4)$$

$$Tpot = Epan(1-exp(-0.55LAI)) \quad (5)$$

whereEpan is daily pan evaporation (mm) and Epot and Tpot are potential evaporation and transpiration (mm).

Equation related to the LAR (Leaf Area Ratio) for the stages before flowering as proposed by Ziaei and Sepaskhah (2003) is as follows:

$$LAR=min\ (220,\ 238-\ 0.846\times EOS + 0.0009 \times EOS^2)*0.67 \quad (6)$$

It is modified to:

$$LAR = min\ (220\ ,\ 258-0.846 \times EOS + 0.0009 \times EOS^2) \quad (7)$$

where EOS is the accumulative pan evaporation since sowing (mm).

b) Modification in crop yield submodel (CROPY)This submodel was developed to estimate grain yield on the basis of WATLAB submodel. The model calculates the daily increment of dry matter as the product of actual transpiration efficiency i. e.

$$DM(inc) = TE \times AT \quad (8)$$

where DM(inc) is the dry matter increment (kg ha^{-1}), TE, the transpiration efficiency (kg ha^{-1} mm) and AT, the actual transpiration (mm).

Equation related to transpiration efficiency (TE) as proposed by Ziaei and Sepaskhah (2003) is as follows:

$$TE = 102 – 13E + 0.35E^2 \quad (9)$$

It is modified to:

$$TE = 52.45 \quad (10)$$

where E is daily pan evaporation (mm).

Equation related to total available pre-anthesis biomass for grain (RESTOT) as proposed by Ziaei and Sepaskhah (2003) is as follows:

$$RESTOT = 0.10\times DMA \quad (11)$$

It is modified to:

$$RESTOT = 0.125\times DMA \quad (12)$$

where DMA is total dry matter at anthesis (kg ha^{-1}).

Equation related to potential growth rate (mg per day) (GR_2) as proposed by Ziaei and Sepaskhah (2003) is as follows:

$$GR2 = GRmax\times 1.5^{(0.47E-2.38)} \quad (13)$$

It is modified to:

$$GR2 = GRmax\times 1.5^{(0.47E-5.08)} \quad (14)$$

where GRmax is the maximum grain growth rate (mg per day).

Table 2. Dry matter and grain yield of winter wheat cultivar Shiraz estimated by MEDIWY model and observed yield in 2007-2008 and 2008-2009 growing season in Badjgahregion

Growing season	Irrigation treatments	Dry matter yield (kg/ha)		Grain yield (kg/ha)	
		Estimated	Observed	Estimated	Observed
2007-2008	100%	24780	27059	5191	5259
	75%	23375	19918	4921	4418
	50%	19508	15710	4177	3480
2008-2009	100%	27474	28582	5444	5642
	75%	26469	21755	5253	4775
	50%	22655	18283	4528	4353

RESULTS AND DISCUSSION

Model Calibration and Validation

Results of model calibration (2008-2009 growing season) and validation (2007-2008 growing season) are given in Table 2. Results of model calibration and validation presented an acceptable estimate of dry matter (straw plus grain yield) and grain yield of winter wheat cultivar Shiraz. Whereas, according to the results of the Ziaei and Sepaskhah (2003), for dry matter estimation of wheat cultivar Adle by MEDIWY model, there were some differences between observed and estimated values. This might have been due to higher dry matter that was obtained for Shiraz cultivar. Correlation coefficient between estimated and observed values of dry matter and grain yield for model calibration were 0.985 and 0.997, respectively and for model validation were 0.982 and 0.994, respectively. The slope of the line drawn between estimated and observed values of dry matter and grain yield (obtained by linear regression analysis, SPSS software) for model calibration were 0.902 and 0.971, respectively and for model validation were 0.936 and 0.927, respectively that were close to 1.0.

Irrigation scheduling under precipitation uncertainty

The seasonal precipitation variation in winter wheat growing season over the last 25 years is shown in Fig. 1. In this Fig., a descending trend is presented. Statistical analysis showed that the slope of trend line (slope of line = -9.554) added to these data was statistically different from the zero slope (horizontal line) (at $\alpha = 0.05$, p-value = 0.041). In this worth mentioning that two data points because of being outliers were removed from the analysis.

Concerning the pessimistic scenario of precipitation uncertainty (i. e., the trend of annual precipitation decrease which was assumed to continue like the preceding years), the average precipitation in the next 20 years was 176 mm. Given the precipitation data of previous 25 years, this value is closest to the precipitation of 1999-2000 growing season (213 mm). This crop season was selected and irrigation scheduling was performed for this growing season (Table 3). According to these results, the irrigation depth related to highest WRF (0.8) was approximately 36% of irrigation depth compared to full irrigation. This might be because of the fact that deficit irrigation was applied only in spring.

Table 3. Irrigation depth (mm) in different WRF and different methods of DIS during the growing season in the pessimistic scenario of precipitation uncertainty (1999-2000) (application efficiency = 100%)

Date	Full irrigation	Deficit irrigation coefficient									
		Method 1					Method 2				
		0.2	0.4	0.6	0.8	1.0	0.2	0.4	0.6	0.8	1.0
31 October 1999	110	110	110	110	110	110	110	110	110	110	110
27 December 1999	37	37	37	37	37	37	37	37	37	37	37
21 March 2000	56	45	34	22	11	−	56	56	56	56	−
26 March 2000	42	34	25	17	8	−	42	42	42	42	−
7 April 2000	58	46	35	23	12	−	58	58	58	16	−
16 April 2000	63	50	38	25	13	−	63	63	63	−	−
24 April 2000	60	48	36	24	12	−	60	60	9	−	−
4 May 2000	77	62	46	31	15	−	77	63	−	−	−
12 May 2000	68	54	41	27	14	−	68	−	−	−	−
19 May 2000	65	52	39	26	13	−	32	−	−	−	−
28 June 2000	81	65	49	32	16	−	−	−	−	−	−
Total	717	603	489	375	261	147	603	489	375	261	147

In contrast, concerning the optimistic scenario of precipitation uncertainty (i. e., a reversing trend of annual precipitation decrease that was assumed to continue for the period 2010-2030), the average precipitation in the next 20 years was 434 mm, which was closest to precipitation data obtained in 2003-2004 growing season (416 mm). For this growing season, irrigation scheduling was determined (Table 4).

Table 4. Irrigation depth (mm) in different WRF and different methods of DIS during the growing season in the optimistic scenario of precipitation uncertainty (2003-2004) (application efficiency = 100%)

Date	Full irrigation	Deficit irrigation coefficient									
		Method 1					Method 2				
		0.2	0.4	0.6	0.8	1.0	0.2	0.4	0.6	0.8	1.0
31 October 2003	110	110	110	110	110	110	110	110	110	110	110
20 April 2004	68	54	41	27	14	−	68	68	68	68	−
30 April 2004	72	58	43	29	14	−	72	72	72	21	−
9 May 2004	73	58	44	29	15	−	73	73	38	−	−
17 May 2004	69	55	41	28	14	−	69	54	−	−	−
24 May 2004	66	53	40	26	13	−	66	−	−	−	−
6 June 2004	97	78	58	39	19	−	8	−	−	−	−
Total	555	466	377	288	199	110	466	377	288	199	110

The number of full irrigation events in 1999-2000 growing season was 11 and reduced to 7 in the 2003-2004 growing season. The total amounts of seasonal irrigation water were 717 mm and 555 mm in 1999-2000 and 2003-2004, respectively. Because of higher precipitation in 2003-2004, the date of the second full irrigation event in the optimistic scenario was 20 April while in 1999-2000 (pessimistic scenario) 6 full irrigation events were needed before this date.

In this research, the difference between the values of average precipitation and total seasonal irrigation in the winter wheat growing season (November to May) in the next 20 years for pessimistic and optimistic scenarios (258 mm and 162 mm for average precipitation and total seasonal irrigation, respectively) was considerably greater than those obtained by Popova and Pereira (2008) (50 mm and 35 mm for average precipitation and total seasonal irrigation, respectively) for the maize growing season (May to September). This difference could be attributed to the higher drought occurrence in the last three decades in our study area (Badjgah) compared with Popova and Pereira (2008) study area (Thrace plain, Bulgaria).

Comparison between our findings and those of Popova and Pereira (2008) indicated that the application of deficit irrigation according to sensitivity of crop growth stages to water stress resulted in more water saving and higher net income.

Estimation of Grain Yield

Results of estimated grain yield are given in Table 5. Implementing the first method of DIS, in the both scenarios of precipitation uncertainty, with the WRF of 0.2, the grain yield decreased very little. However, with the increase in WRF, greater reduction in grain yield was obtained. While using the second method of DIS, even with WRF of 0.4 the grain yield did not decrease. This indicated that the last two irrigation events are not effective in grain yield production. Furthermore, WRF of 0.6 in the second method of DIS did not reduce the grain yield substantially. Even at high WRF (0.8 and 1.0) considerable grain yield was obtained (greater than 2500 kg ha^{-1}). In general, grain yield in the second method of DIS was higher than those in the first method. The difference between the two methods of DIS was maximized at WRF of 0.6. Therefore, the second method of DIS (leading to the reduction in the number of irrigation events) is preferred.

Table 5. Grain yield (kg/ha) in different WRF, application efficiency (E_a) and methods of DIS during the growing season in the pessimistic and optimistic scenario of precipitation uncertainty (1999-2000 and 2003-2004, respectively)

Water reduction fraction	Application efficiency (%)											
	pessimistic scenario						optimistic scenario					
	Method 1			Method 2			Method 1			Method 2		
	100	80	60	100	80	60	100	80	60	100	80	60
0.0	4989	4989	4989	4989	4989	4989	4936	4936	4936	4936	4936	4936
0.2	4858	4989	4989	4989	4989	4989	4807	4936	4936	4936	4936	4936
0.4	4260	4728	4989	4989	4989	4989	4360	4714	4936	4936	4936	4936
0.6	3631	3940	4468	4702	4949	4961	3819	4093	4524	4572	4854	4936
0.8	3030	3185	3423	3678	3961	4107	3310	3429	3650	3787	3999	4335
1.0	2584	2584	2584	2584	2584	2584	2918	2918	2918	2918	2918	2918

Decreasing the irrigation application efficiency resulted in lower reduction in grain yield due to higher depth of irrigation water related to each WRF. Therefore, at E_a of 60% and WRF<=0.4, there was no reduction in grain yield at both precipitation uncertainty scenarios and methods of DIS. Furthermore, differences in grain yield between the first and second methods of DIS decreased as E_a decreased. The differences are higher in pessimistic scenario than those in optimistic scenario due to higher precipitation in latter scenario. Grain yield obtained at WRF of 0.0 (i. e., full irrigation) in the pessimistic scenario is a little higher than that in the optimistic scenario. This might be because of the fact that in the pessimistic scenario, more irrigation water was used in spring. However, by increasing the WRF, the effect of precipitation was higher, so that at WRF>0.2 (E_a=100% and first method of DIS) the grain yield related to the optimistic scenario was higher than those obtained in the pessimistic scenario.

Estimation of Net Income

The cost of unit cubic meter of water for use in agriculture was calculated as 598 Rls for the study region. Hence, based on this water price, the net income (NI) for the above mentioned situations was calculated. The results of net income for different E_a, climatic scenarios, methods of DIS and WRF are given in Fig. 2.

For the first method of DIS, the maximum net income ($5*10^6$Rls ha^{-1}) was obtained in the optimistic scenario, as follows: E_a= 100% and WRF=0.2. This was due to lower irrigation water cost and lower irrigation labor costs. For the second method of DIS, the maximum net income ($6.2*10^6$Rls ha^{-1}) was obtained in the optimistic scenario, as follows: E_a= 100% and WRF=0.4.

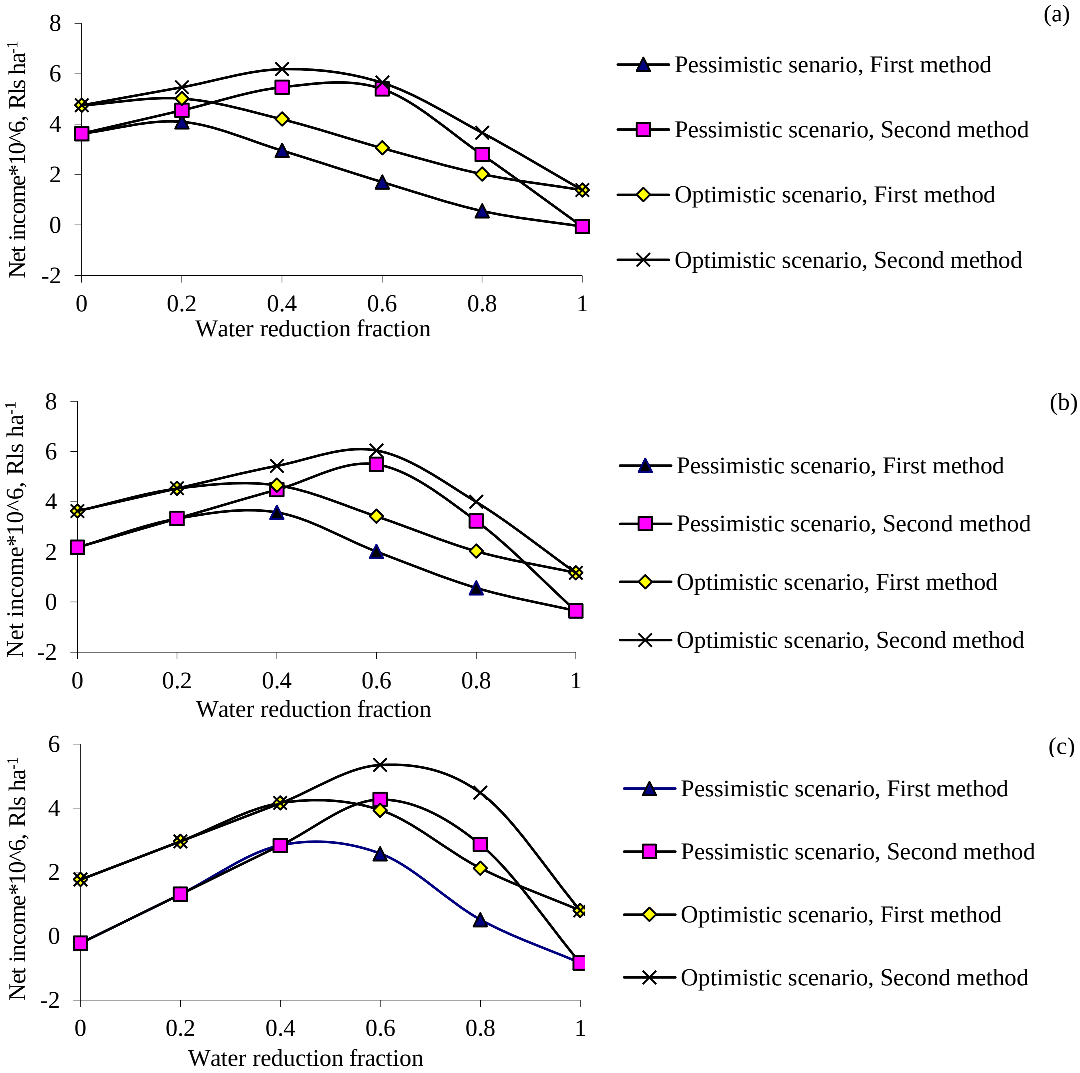

Fig. 2. Trend of net income variations with different WRF, scenarios of precipitation uncertainty, methods of DIS and different irrigation application efficiency (E_a=100% (a), 80% (b), and 60% (c))

This was due to lower irrigation water cost and lower irrigation labor costs. The minimum net income for the first and second methods of DIS ($-0.84*10^6$Rls ha^{-1}) was obtained in the pessimistic scenario, E_a=60% and WRF=1.0. Negative NI values was obtained only in the pessimistic scenario (at WRF=1.0 for all E_a values and WRF=0.0 only for E_a=60%). By decreasing E_a, NI values in the first method of DIS (for both climatic scenarios) decreased for WRF=0.0 and 0.2. This decrement in the second method of DIS was observed at WRF=0.0, 0.2 and 0.4. Using WRF values, other than those just mentioned, by decreasing E_a, NI values initially increased and then decreased and for the higher WRF, the maximum value of NI was obtained at lower E_a (for both climatic scenarios). By increasing WRF (increasing water deficit), NI values initially increased and then decreased for all values of E_a. By decreasing E_a values, the maximum value of NI was close to higher WRF; meanwhile, this WRF for the second method of DIS was higher than the values obtained for the first method of DIS. The net income obtained in the optimistic scenario in all cases was higher than those obtained in the pessimistic scenario due to the higher precipitation with the exception of NI values obtained at WRF=0.6 and 0.8 for E_a=60%, 70% (data not shown) and 80% and WRF=0.4, 0.6 and 0.8 for E_a=90% (data not shown) and 100%. In these cases, the NI values obtained for the second method of DIS in the pessimistic scenario was higher than those obtained for the first method of DIS in the optimistic scenario. The NI values obtained for the first and second methods of DIS at E_a=100% under both climatic scenarios were equal only for WRF=0.0 (full irrigation). By decreasing E_a values, this equality occurred at higher WRF because of application of higher irrigation water at sensitive stages of growth (joining and flowering) at lower E_a values.

CONCLUSIONS

The modified MEDIWY model, calibrated and validated for winter wheat (cv. Shiraz) yield, appeared to be successful. This model was used to simulate the effect of precipitation uncertainty and deficit irrigation on irrigation scheduling and grain yield of winter wheat. The effects of two methods of deficit irrigation scheduling on grain yield were compared under different precipitation scenarios. Seasonal irrigation depth in the pessimistic scenario was 717 mm (precipitation was equal to 213 mm) and in the optimistic scenario it was 555 mm (precipitation was equal to 434 mm). In this research, deficit irrigation was applied only in spring because most of irrigation events for winter wheat crop were applied in this season. The results indicated that the second method of DIS (reduction in the number of irrigation) was preferred mainly due to obtaining more grain yield than the first method of DIS with higher WRF because of negligible importance of the last irrigations in growing season.

Therefore, application of the second method of DIS is recommendable for other crops especially winter crops. One of the main findings of the study is that farmers are more satisfied because they can obtain the products at lower price by applying the first irrigation only. Therefore, in semi-arid areas where the first irrigation only can be applied and there is no water for irrigation in spring, cultivation of winter wheat is recommendable. In most cases, the NI obtained in the optimistic scenario was higher than those obtained in the pessimistic scenario. It should be noted that negative NI values obtained in this research, is for conditions considering land rent, costs of drilling well, pumping and labor. While for farmers that do not pay for these costs, the net income is not negative. The maximum net income in both scenarios of precipitation uncertainty, following the first method of DIS was obtained at WRF=0.2 and for the second method of DIS it was at WRF=0.4. Therefore, with less water consumption, in addition to protecting water resources, farmers will earn more income, verifying the priority of the second method of DIS. Therefore, the second method of DIS is recommended for different situations.

The maximum net income is not obtained in full irrigation under all conditions, indicating an economical performance of deficit irrigation. Therefore, proper management of water resources in agricultural sector is feasible via appropriate deficit irrigation scheduling.

REFERENCES

Abdollahi Ezzatabadi, M. (1996). Economic analysis of alternatives for supply of agricultural water in Rafsanjan. M.Sc. Thesis. Agricultural Economics Department (Unpublished). Shiraz University. Shiraz. I. R. Iran. 197 p.

Allen, R.G., Pereira, L.S., Raes, D., & Smith, M. (1998). Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage paper 56, Rome, 300 p.

Cancela, J.J., Cuesta, T.S., Neira, X.X., & Pereira, L.S. (2006). Modelling for improved irrigation water management in a temperate region of Northern Spain. *Biosystems Engineering,* 94(1), 151–163.

Cordery, I., & Graham, A.C. (1989). Forecasting wheat yields using a water budgeting model. *Australian Journal of Agricultural Research,* 40, 715-728.

English, M.J., & Raja, S.N. (1996). Every other furrows of corn irrigation. *Transaction of the ASAE,* 17, 426-428.

Fateh, M. (2010). Investigation of the effect of different levels of irrigation and seed rates on Shiraz cultivar wheat yield with surface irrigation in Badjgah area (Fars province). M.Sc. Thesis. Irrigation Department (Unpublished). Shiraz University. Shiraz. I. R. Iran. 145 p.

Geerts, S., Raes, D., & Garcia, M. (2010). Using AquaCrop to drive deficit irrigation schedules. *Agricultural Water Management,* 98, 213-216.

Misra, S.C., Shinde, S., Geerts, S., Rao, V.S., & Monneveux, P. (2010). Can carbon isotope discrimination and ash content predict grain yield and water use efficiency in wheat? *Agricultural Water Management,* 97, 57-65.

Pereira, L.S., van den Broek, B., Kabat, P., & Allen, R.G. (1995). Crop–Water Simulation Models in Practice. Wageningen Press, Wageningen. 322 p

Pereira, L.S., Paredes, P., Eholpankulov, E.D., Inchenkova O.P., Teodoro, P.R., & Horst, M.G. (2009). Irrigation scheduling strategies for cotton to cope with water scarcity in the Fergana Valley, Central Asia. *Agricultural Water Management,* 96, 723-735.

Pereira, L.S., Oweis, T., & Zairi, A. (2002). Irrigation management under water scarcity. *Agricultural Water Management,* 57, 175–206.

Popova, Z., & Pereira, L.S. (2008). Irrigation scheduling for furrow-irrigated maize under climate uncertainties in the Thraceplain, *Bulgarian Biosystems Engineering,* 99, 587-597.

Razzaghi, F., & Sepaskhah, A.R. (2012). Calibration and validation of four common ET_0 estimation equations by lysimeter data in a semi-arid environment. *Archives of Agronomy and Soil Science,* 58(3), 303-319.

Rodrigues, G.C., & Pereira, L.S. (2009). Assessing economic impacts of deficit irrigation as related to water productivity and water costs. *Biosystems Engineering,* 103, 536-551.

Sepaskhah, A.R., Azizian, A., & Tavakoli, A.R. (2006). Optimal applied water and nitrogen for winter wheat under variable seasonal rainfall and planning scenarios for consequent crops in a semi-arid region. *Agricultural Water Management,* 84, 113-122.

Sepaskhah A.R., & Tafteh, A. (2012). Yield and nitrogen leaching in rapeseed field under different nitrogen rates and water saving irrigation. *Agricultural Water Management,* 112, 55-62.

Sepaskhah, A.R., & Akbari, D. (2005). Deficit irrigation planning under variable seasonal precipitation. *Biosystems Engineering,* 92(1), 97–106.

Sepaskhah, A.R., & Ghahraman, B. (2004). The Effects of Irrigation Efficiency and Uniformity Coefficient on Relative Yield and Profit for Deficit Irrigation. *Biosystems Engineering,* 87 (4), 495–507.

Smith, M., Pereira, L.S., Berengena, J., Itier, B., Goussard, J., Ragab, R., Tollefson, L., & Van Hoffwegen, P. (1996). Irrigation Scheduling: From Theory to Practice. FAO Water Report 8, FAO, Rome, 384 p.

Ziaei, A.N., & Sepaskhah, A.R. (2003). Model for simulation of winter wheat yield under dryland and irrigated conditions. *Agricultural Water Management,* 58, 1-17.

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برنامه بندی آبیاری و تخمین عملکرد دانه گیاه گندم زمستانه، تحت شرایط عدم قطعیت آب و هوایی – مطالعه موردی در منطقه باجگاه (استان فارس، ایران)

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درآمد خالص

چکیده- پرداختن به برنامه بندی کم آبیاری محصولات استراتژیک (مخصوصاً گندم) تحت شرایط عدم قطعیت آب و هوایی در شرایط فعلی یک اولویت می باشد. ما عدم قطعیت آب و هوایی را با شبیه سازی دو سناریو خوش بینانه و بدبینانه برای ۲۰ سال آینده بررسی کردیم که این بررسی با استفاده از داده های آماری هواشناسی ثبت شده در منطقه مورد مطالعه انجام شد. برنامه بندی کم آبیاری در فصل بهار به دو طریق انجام شد: (۱) کاهش در مقدار آب آبیاری در هر یک از وقایع آبیاری. (۲) کاهش تعداد وقایع آبیاری کامل. نتایج نشان دادند که به دلیل تأثیر افزایش بارندگی در افزایش عملکرد، عملکرد دانه در سناریو خوش بینانه بالاتر است. همچنین عملکردهای دانه به دست آمده در روش دوم برنامه بندی کم آبیاری بیشتر از روش اول است و با افزایش کسر کاهش آب تا ۰/۶، این اختلاف بیشتر می شود. این نشان می دهد که وقایع آبیاری مربوط به ابتدای فصل بهار اهمیت خیلی بیشتری نسبت به آبیاری های آخر فصل بهار دارد. در راندمان های پایین کاربرد آب در مزرعه، اختلاف قابل ملاحظه ای بین روش های برنامه بندی آبیاری در کسرهای بالاتر کاهش آب مشاهده شد. درآمد خالص به دست آمده در روش برنامه بندی کم آبیاری دوم در تمام شرایط از روش اول بیشتر بود که این به دلیل کاهش تعداد وقایع آبیاری و در نتیجه کاهش هزینه های تولید در روش دوم نسبت به روش اول می باشد. نهایتاً نتایج نشان داد که در هر دو سناریو عدم قطعیت آب و هوایی، روش دوم برنامه بندی کم آبیاری ارجح می باشد.