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Consideration of Water Productivity for Farm Water Management in Different Conditions of Water Availability for Dominant Summer Crops

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ABSTRACT- Efficient use of irrigation water for summer crops should be considered seriously due to rare occurrence of precipitation in summer. This research was focused on the assessment of water use efficiency for dominant crops of summer cropping pattern in the study area (i.e., maize and rice) via considering water productivity (WP) with different water management scenarios at farm level at different climatic conditions. Results indicated that in most cases the maximum WP was not occurred at full irrigation scenario. With increasing irrigation application efficiency (Ea), WP increased and the maximum WP shifted toward higher water reduction fraction (WRF). For maize, in deficit irrigation scheduling (DIS) methods with full irrigation at flowering stage, more deficit irrigation application was economically acceptable. For rice, with increasing Ea and WRF, WP increased and deficit irrigation at different growth stages was economically acceptable. Considering the real cost of water, economic water productivity ratio (EWPR) decreased greatly and in surface irrigation system, Ea should be increased and high WRF should be avoided (WRF should be lower than 0.4). In solid-set sprinkler system, EWPR increased with increasing Ea and application of WRF higher than 0.2 (0.2-0.6 for maize) was acceptable. Tape irrigation of maize was acceptable only for WRF less than 0.2; also, 0.2-0.4 was acceptable for WRF by decreasing the Ea.

Keywords: Deficit irrigation scheduling, Economic water productivity, Irrigation application efficiency, Net income, Water cost

INTRODUCTION

In semi-arid areas total precipitation occurs at late fall, winter and early spring and there is no rainfall in summer growing season. Therefore, water consumption in agriculture (main user of limited water resources) should be efficient and managed carefully especially with the occurrence of drought in recent years. Increasing water productivity (WP), especially economic water productivity may be the best way to achieve efficient water use (15).

Depending on how the terms in the numerator and denominator are expressed, WP can be expressed in general physical or economic terms (15,16). When different water

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management scenarios in farm at different scales are being examined, a physical term of WP does not suffice and the WP increase should be achieved with economic outlook. Namely, the maximum economic water productivity (EWP) i.e., the value derived per unit of water used, should be determined. In order to achieve this purpose, different irrigation scenarios during growing season and different irrigation systems with different application efficiencies (Ea) for applying available water have important roles. In other words, crop WP or water use efficiency (WUE), as reviewed by Molden (10), is a key term in the evaluation of deficit irrigation (DI) strategies (6). Various irrigation scenarios can be imposed through the DI that consist of deliberately applying irrigation depths smaller than those required to satisfy the crop water requirements at certain periods in the growing season. Therefore, it affects evapotranspiration and yields, but keeps a positive return from the irrigated crop (5, 7). However, the impacts of DI on yield and related economic results may or may not be negative, depending upon the irrigation scheduling adopted, the irrigation system performance, the production costs and the yield values (8, 15). It should be noted that stages of crop growth are very important for application of DI and sensitive stages of crop growth should be fully irrigated or limited DI should be applied at these stages as far as possible.

Therefore, proper management of water resources in irrigation districts ould be considered. The objective of this research was to evaluate different deficit irrigation scheduling (DIS) scenarios by using economic aspects of WP related to dominant summer crops irrigated with different irrigation systems and Ea at different climatic conditions in Doroodzan Irrigation District in the south of Islamic Republic (I. R.) of Iran.

MATERIALS AND METHODS

This study was conducted at Doroodzan Irrigation District with area of approximately 64000 ha located at south of I. R. of Iran. The meteorological station is located in Kooshkak Agricultural Research Station, Shiraz University (longitude of 52.57° N, latitude of 30.12° E and 1650 m above mean sea level). Summary of the average meteorological data that calculated for 36 water years of recorded data are presented in Table 1. Water year is the period of beginning of October of last year to end of September of later year. The predominant soil type at the site is silty clay.

Irrigation Scheduling, Scenarios And Systems

Crops as the dominant plants of cropping pattern in the study region in summer growing season are maize and rice. The approximate crop development stage periods of maize are June 2 to June 22, June 23 to July 26, July 27 to September 2 and September 3 to October 1, for initial, development, mid-season and late season stages, respectively. These periods for rice are June 29 to July 17, July 18 to August 14, August 15 to September 21 and September 22 to October 8, respectively.

Irrigation scheduling of these crops was determined for wet, normal and drought water year. These water years were selected among 36 water years of available meteorological data. Therefore, the annual precipitations for these 36 water years were used. Then, using the Weibull Eq. (3), the probability of occurrence (P(x)) of water year precipitation, was calculated as follows and the water years in relation to the probability of precipitation occurrence of 20%, 50% and 90% were selected as wet, normal and drought water years, respectively:

$$P(x) = \frac{r}{N+1} \tag{1}$$

Where P(x) is the probability of occurrence of the precipitation greater than or equal to "x", "r" is the number of row associated with particular precipitation in the data set when data are arranged from high to low and N is the total number of data (number of water years of recorded data).

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

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum temperature, °C	12.4	14.2	15.9	22.1	27.4	32.7	34.6	34.5	30.3	25.9	19.8	13.8
Minimum temperature, °C	-1.8	-1.2	2.8	6.1	9.4	13.2	17.1	15.6	10.8	6.3	2.8	-0.7
Mean relative humidity, %	60.6	64.4	63.8	57.8	53.9	50.2	43.3	46.7	43.8	46.7	55	57.7
Wind speed, m s^{-1}	0.4	0.7	0.7	0.6	0.7	1.2	0.5	0.6	0.5	0.5	0.4	0.3
Sunshine duration, h d^{-1}	7	7.1	7.1	7.8	9.6	11.3	10.6	10.1	9.9	7.9	7.5	6.5
Precipitation, mm	86.8	60.9	40.3	36.0	15.5	0.0	0.0	0.0	0.0	27.9	33.0	102.3
ET_o, mm d^{-1}	2.4	3.5	3.6	5.0	6.2	8.0	8.2	8.1	6.2	4.7	3.0	2.1

For full irrigation scheduling and irrigation application efficiency (Ea) of 100%, the quantity of irrigation was considered equal to crop potential evapotranspiration (ETc) and irrigation water was applied when readily available water of soil was used. ETc was calculated using FAO dual crop coefficient method (2). Solution consisted of splitting Kc into two separate coefficients, one for crop transpiration, i.e., the basal crop coefficient (Kcb), and another for soil evaporation (Ke) (2):

$$ET_c = (K_{cb} + K_e)ET_o \tag{2}$$

Where ETo is the reference crop evapotranspiration, in mm d-1 and was calculated by using the FAO Penman-Monteith method that has been modified for this study region by Razzaghi and Sepaskhah (13). For maize the Kcb and Ke coefficients were obtained from Shahrokhnia and Sepaskhah (17).

Irrigation scenarios for rice consisted of three irrigation regimes (1) as: 1) continuous flooding irrigation, 2) intermittent flooding irrigation with 1 day interval and 3) intermittent flooding irrigation with 2 days interval.

For applying deficit irrigation (DI) for maize, four water reduction fractions (WRF, i. e., 0.2, 0.4, 0.6 and 0.8) and several methods of deficit irrigation scheduling (DIS) (1, 2, 3, 4 and 5) were used that are described as follows:

Method 1: Relative applied water (1-WRF) i. e., 0.8, 0.6, 0.4 and 0.2 are multiplied by quantity of each irrigation event calculated for stages after establishment in spring or summer.

Method 2: Relative applied water (1-WRF) are multiplied by the total number of irrigation events obtained for stages after establishment. However, full irrigation was applied at the reduced number of irrigation events.

Methods 3, 4 and 5: Full irrigation was applied at vegetative stage in method 3, at vegetative and flowering stages in method 4 and at flowering stage in method 5. For other stages, (1-WRF) are multiplied by the quantity of water at each irrigation event.

Meanwhile, the period of vegetative, flowering, yield formation and ripening stages are 43, 24, 22 and 16 days, respectively.

For rice, the scheduling methods are as follows:

Method 1: Relative applied water (1-WRF) are multiplied by quantity of water at each irrigation event calculated for stages after establishment in summer.

Methods 2, 3 and 4: Full irrigation was applied at tillering stage in method 2, at tillering and heading stages in method 3 and at tillering, heading and flowering stages in method 4. For other stages; (1-WRF) are multiplied by quantity of water at each irrigation event.

In this study for maize, different irrigation systems with various Ea were compared that are surface irrigation (Ea= 30%, 40%, 50% and 60%), solid-set sprinkler irrigation (Ea= 50%, 60%, 70% and 80%) and tape irrigation (Ea= 70%, 80% and 90%). For rice only surface irrigation (Ea= 50%, 60% and 70%) was considered.

Water Productivity

Farm irrigation water productivity (WPI-Farm) is defined here as the ratio of the actual crop yield to the irrigation water use (IWU), in kg m-3 (15):

$$WP_{I-Farm} = \frac{Y_a}{IWU} \tag{3}$$

where Ya is the actual yield (grain yield), in kg, and IWU is the irrigation water use not including precipitation (because precipitation in the study region usually occurs in winter and early spring seasons), in m3, to achieve Ya.

Economic aspects of water should be considered because the objective of the farmer is to achieve the best income and profit. For this purpose the farm irrigation economic water productivity (EWPI-Farm) is defined as the ratio of the value of actual grain yield to the irrigation water use, in Rls m-3 (15):

$$EWP_{I-Farm} = \frac{Value\,(Y_a)}{IWU} \tag{4}$$

where value (Ya) is the value of actual yield, in Rls, and IWU is the irrigation water use, in m3.

For calculating the value of actual yield, the prices per kilograms of actual yields of crops were obtained from Agricultural Organization of Fars province (I. R. of Iran). These prices for the year 2011 are 3929 and 17391 Rls kg-1 for maize and rice, respectively.

The economics of production may be understood when the numerator is expressed in terms of gross margin or net income for the considered crop (14). Easier to work, alternatively the economics of production is considered when expressing both the numerator and the denominator in monetary terms, respectively, i.e., the yield value and the IWU cost. Therefore, it results in EWP ratio (EWPR) that is defined as the ratio of the value of actual yield to the cost of irrigation water use, (15):

$$\mathbf{EWPR} = \frac{\mathrm{Value}\ (Y_a)}{\mathrm{Cost}\ (IWU)} \quad (5)$$

where value (Ya) is the value of actual yield, in Rls, and cost (IWU) is the cost of irrigation water use, in Rls.

Use of EWPR provides the possibility of comparing the effects of real and current cost of water and obtaining better decisions in different conditions. In the study region, the cost of a cubic meter of IWU was calculated using the published information of Fars province Regional Water Organization. Given this information, current cost of water is calculated according to water right paid by farmers of the study region (3% of value of actual yield), leading to different costs of water for different crops. For calculating the real cost of water, the fixed and variable costs were considered. The fixed cost is defined here as the ratio of the investment costs to total water use and the variable cost is defined here as the ratio of operation, maintenance and management costs to total water use.

In this study two scenarios of irrigation water cost are considered, i.e. current cost and real cost of irrigation water that current cost was calculated 84 and 87 Rls m-3 for maize and rice, respectively and real cost was calculated as 1150 Rls m-3. For calculating real cost of water, initially the costs of Doroodzan dam and irrigation network construction converted to uniform annual cost by using Capital Recovery formula. Then they were added to the annual costs of irrigation network operation, maintenance and management. Finally the unit real cost of water was calculated by dividing this total annual cost by the maximum volume of delivered water to the irrigation network.

Actual grain yield estimation

For estimating actual grain yields at different quantities of irrigation water, the potential yields (Ym) were estimated using the agro-ecological zone (AEZ) method proposed by Doorenbos and Kassam (4). Results were validated by comparing them with the maximum grain yields obtained in the region. Then actual grain yield (Ya) was obtained using the Eq. proposed by Meyer et al. (9) as follows:

$$\frac{Y_a}{Y_m} = \prod_i^n \left(\frac{W_{ai}}{W_{pi}}\right)^{\lambda i} \quad (6)$$

Where Wai is the actual water used in deficit irrigation scheduling at stage i, mm, Wpi is the potential water requirement at stage i that equals to quantity of full irrigation at Ea=100%, mm, and λi is the sensitivity index of crop to water deficit at stage i. In this research, λi values for maize that presented by Nairizi and Rydzewski (11) were used after modification for the study region. For rice, we could not find any values for the λi for different stages of growth in literature. Therefore, the values presented by Sepaskhah (personal communications, 2011) were used. Values of λi for maize are equal to 0.372, 0.558, 0.078 and 0.090 for vegetative, flowering, yield formation and ripening stages, respectively. For rice, the values of λi at all growth stages were considered equal to 0.65 with assumption of equal sensitivity of all stages to water reduction.

In cases with use of low irrigation application efficiencies, it is likely that the relative yield is equal or greater than 1.0. Even in these cases, there should be different net income due to difference in volume of applied water and the related costs.

Net income

For assessment of impacts of water costs under different irrigation systems, in addition to EWPR, net income (NI= gross income minus production cost) earned per unit area (hectare) for different irrigation systems was determined by using Eq. (7) as
production cost:

$$C = a_1 + b_1 W \tag{7}$$

where C is the total production cost, in Rls ha , W is the water used, in m ha and “a1” and “b1” are parameters. The production cost is divided into two parts: fixed and variable costs. Fixed cost (a1) includes land rent, cultivation operation cost and irrigation system equipments and designing costs. Variable cost (b1) includes applied water cost, labor and yield transportation costs that indirectly were associated with the water used in the unit area by equalizing the working days and transported yield by the water used. According to the information obtained from Agricultural Organization of Fars province (I. R. of Iran) for year of 2011 (personal communication), the fixed costs of maize production were calculated as 8×106, 6.2×106 and 15.4×106 Rls for surface, solid-set sprinkler and tape irrigation systems, respectively and the fixed cost of rice production was calculated as 13.7×106 Rls for surface irrigation system. The labor and yield transportation costs were considered equal to 140000 Rls per day (8h) and 80 Rls kg-1 according to the local information.

RESULTS AND DISCUUSION

Irrigation Water

The water years of 1977/1978, 1985/1986 and 1993/1994 was determined as wet, normal and drought water years, respectively. Results of net irrigation requirement in summer growing seasons of different experimental water years (i. e., wet, normal and drought), crops, WRF (i. e., 0.0, 0.2, 0.4, 0.6 and 0.8) and methods of DIS (i. e., methods 1-5 for maize and 1-4 for rice) are given in Table 2. It is indicated that in growing season of drought water year, irrigation water depth increased. However, this increase is not high. ETc for maize were estimated as 762, 813 and 855 mm for growing seasons of wet, normal and drought water year, respectively and for rice were estimated as 1258, 1305 and 1384 mm, respectively (2). The basal crop coefficient (Kcb) for maize was estimated 0.071, 1.21 and 0.157 for initial, mid season and end, respectively. These coefficients for rice were estimated 0.95, 1.15 and 0.70, respectively. The soil evaporation coefficient (Ke) for maize was estimated 0.286, 0.239 and 0.200 for initial, mid season and end, respectively. These coefficients for rice were estimated 0.050, 0.050 and 0.200, respectively.

Grain Yield

The potential grain yields for maize and rice at different water years (wet, normal and drought) were calculated by AEZ method (Ym). The actual grain yields (Ya) of these crops for the different experimental water years, WRF and methods of DIS at Ea=100% were calculated by using Eq. (6). Results are given in Table 3. By increasing WRF, the grain yield decreased, however, for maize this decrease is lower for methods of DIS in which the sensitive stages of growth to water deficit is fully irrigated (method 4) 23.7%) and for rice is lower for methods of DIS in which the higher number of growth stages is fully irrigated (method 4) (38.6%). Nevertheless, on average this decrease was lower for rice (55.7%) compared to maize (63.3%) because of assuming equal sensitivity of different growth stages of rice to water deficit and lower values of the used maximum WRF (0.29 for rice compared to 0.8 for maize).

Table 2. Net irrigation requirements (mm) for different experimental water years (wet, normal and drought), crops, water reduction fractions (WRF) and methods of deficit irrigation scheduling (DIS)

Crops	Methods of deficit scheduling	Net irrigation requirement (mm) at different water years and WRF														
		Wet water year					Normal water year					Drought water year				
		0.0	0.2	0.4	0.6	0.8	0.0	0.2	0.4	0.6	0.8	0.0	0.2	0.4	0.6	0.8
Maize	1	855	710	600	489	379	929	799	670	540	410	957	829	700	572	443
	2	855	710	600	489	379	929	799	670	540	410	957	829	700	572	443
	3	855	752	682	613	543	929	847	765	683	601	957	864	771	679	586
	4	855	780	739	698	657	929	889	850	810	770	957	907	857	808	758
	5	855	739	657	574	492	929	842	754	667	579	957	872	786	701	615
		0.0	0.16	0.29			0.0	0.16	0.29			0.0	0.16	0.29		
Rice	1	1671	1370	1186			1671	1370	1186			1843	1511	1308		
	2	1671	1457	1283			1671	1457	1283			1843	1607	1415		
	3	1671	1511	1380			1671	1511	1380			1843	1666	1522		
	4	1671	1564	1477			1671	1564	1477			1843	1725	1629		

Table 3. Grain yield (kg ha-1) for different experimental water years (wet, normal and drought), crops, water reduction fractions (WRF) and methods of deficit irrigation scheduling (DIS) at Ea=100% (Ym is equal to grain yield at WRF=0.0)

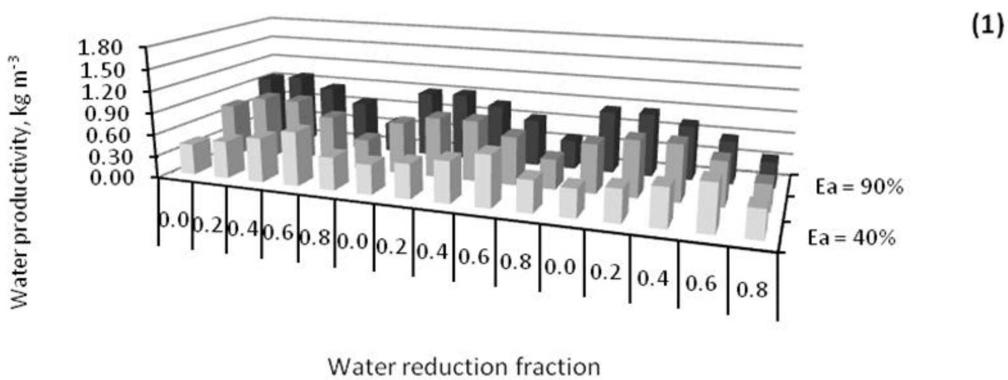
Crops	Methods of deficit scheduling	Grain yield (kg ha^{-1}) at different water years and WRF														
		Wet water year					Normal water year					Drought water year				
		0.0	0.2	0.4	0.6	0.8	0.0	0.2	0.4	0.6	0.8	0.0	0.2	0.4	0.6	0.8
Maize	1	9033	7070	5155	3303	1543	9388	7348	5358	3433	1604	9060	7091	5171	3313	1548
	2	9033	8701	8290	4644	1543	9388	9043	6479	4827	1604	9060	8727	6253	4658	1548
	3	9033	7682	6234	4644	2808	9388	7984	6479	4827	2918	9060	7705	6253	4658	2816
	4	9033	8701	8290	7744	6893	9388	9043	8616	8049	7164	9060	8727	8315	7767	6914
	5	9033	8008	6855	5507	3788	9388	8322	7125	5724	3937	9060	8032	6876	5524	3799
		0.0	0.16	0.29			5685	3226	1868			0.0	0.16	0.29		
Rice	1	5641	2960	1323			5685	3613	2333			5797	3289	1905		
	2	5641	3367	1768			5685	4046	2915			5797	3684	2379		
	3	5641	3831	2363			5685	4532	3642			5797	4126	2973		
	4	5641	4358	3158			5685	3226	1868			5797	4621	3714		

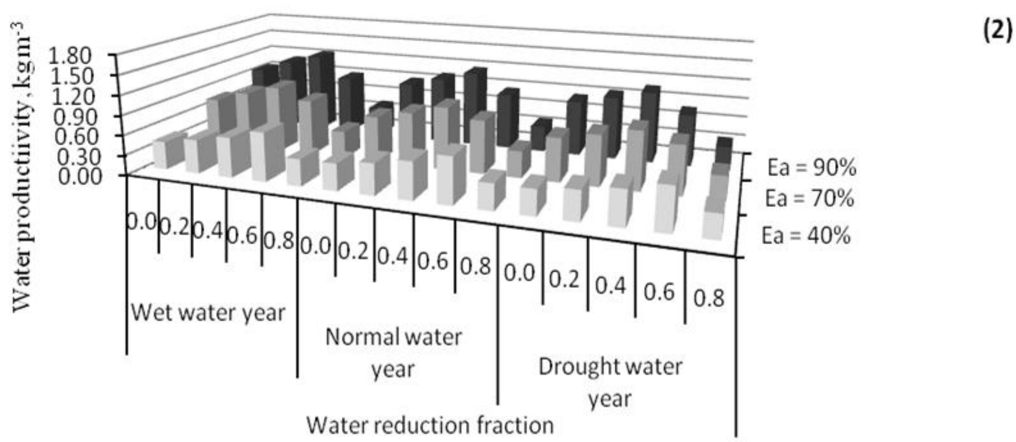
However, in reality this difference might not be occurred due to possible difference in real λi for different stages of growth for rice. For maize, despite the equal irrigation depth of DIS methods for 1 and 2, grain yields obtained in the second method of DIS was on average 19.6% higher than those obtained in the first method of DIS and with increasing the water reduction fraction (WRF) to 0.6, this difference approached about 41% due to more importance of irrigation events at sensitive stages of growth on yield enhancement. Meanwhile, the grain yield obtained at DIS method of 1 was the lowest because of lower irrigation depth at sensitive stages of growth for maize. This was obtained for rice because of lower number of irrigation events in this method. At low irrigation application efficiency (Ea), higher difference in yields between DIS method of 1 and other DIS methods ppeared in higher values of WRF.

Water productivity

Maize

WPI-Farm, for different water years, WRF, Ea values and DIS methods was calculated for maize and the results of Ea= 40%, 70% and 90% are shown in Fig. 1. With rising WRF, WPI-Farm values initially increased and then decreased for all Ea values and different methods of DIS. These fluctuations at methods 4 and 5 of DIS were lower than other methods of DIS; so that the values obtained for WPI-Farm at WRF=0.6 and 0.8 for DIS methods of 4 and 5, respectively, were higher than other methods of DIS.





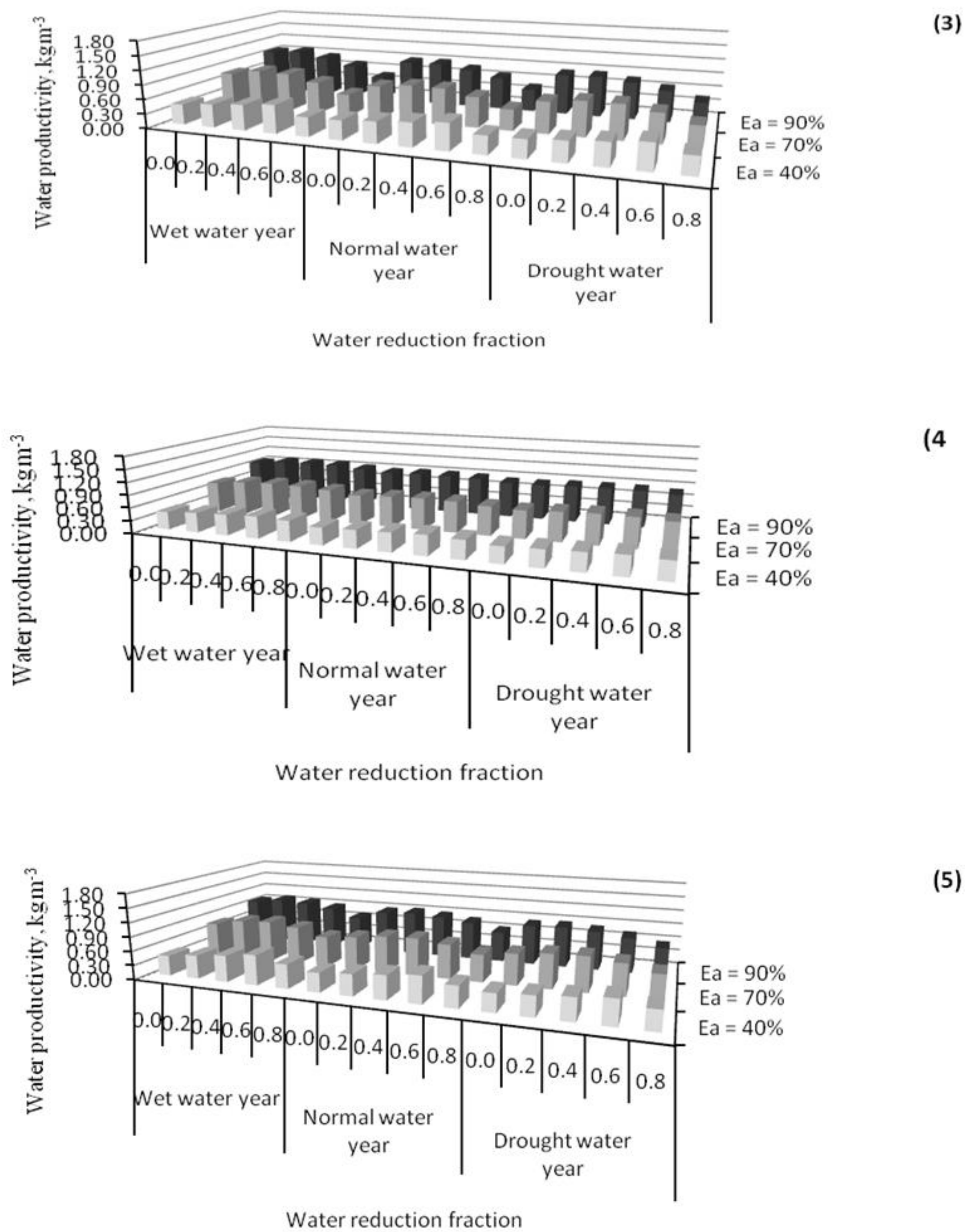


Fig. 1. Water productivity (WPI-Farm) of maize under different methods of deficit irrigation scheduling, water reduction fraction, different experimental water years and irrigation application efficiency (Ea): 1-5 are ifferent methods of deficit irrigation scheduling

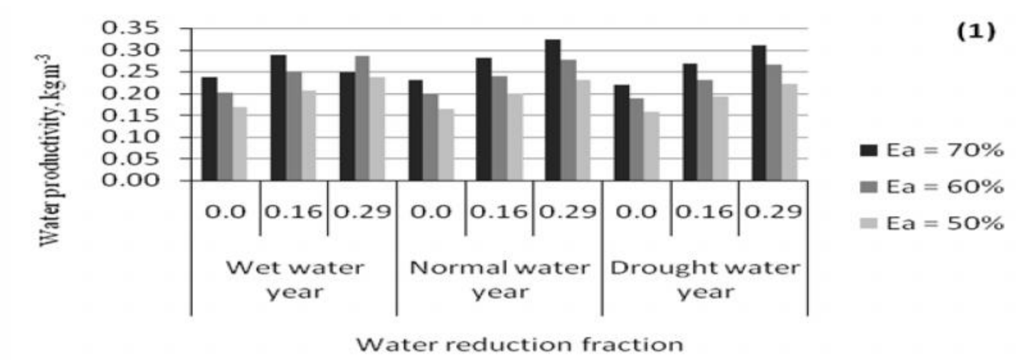
This indicates that with increasing WRF, WPI-Farm does not decrease significantly due to high sensitivity of maize to water deficit at flowering stage, because in DIS methods of 4 and 5, full irrigation was applied at flowering stage. However, at lower values of Ea, the maximum value of WPI-Farm is obtained at higher WRF for all methods of DIS. At Ea=40%, the value of maximum WPI-Farm approximately reduced to half of its value at Ea=90%. This is obtained due to the fact that maize is sensitive to water deficit. In method 2 of DIS [multiplication of (1-WRF) by the number of irrigation events], at higher values of Ea (70% and 90%), the maximum value of WPI-Farm occurred at WRF=0.4 whereas for other methods of DIS, this maximum value occurred at WRF=0.2. This indicated that the irrigation events at the end of growing season are less important due to lower values of λi and it is suggested that in spite of decreasing the number of irrigation events (removing the irrigation events after flowering stage); acceptable WPI-Farm can be achieved. In all conditions, the values of WPI-Farm obtained at DIS method of 5 were greater than those obtained at DIS method of 3 because of higher sensitivity of flowering stage than vegetative stage to water deficit. Meanwhile, for Ea<=60%, these values obtained at DIS method of 5 and 3 were close together, especially at drought water year because of higher irrigation application depth. At high values of Ea, the obtained values of WPI-Farm at DIS method of 5 were higher than or equal to those obtained at DIS method of 4 only at lower WRF. At low values of Ea, the obtained values of WPI-Farm at DIS method of 5 were higher than or equal to those obtained at DIS method of 4 at all values of WRF. The obtained values of WPI-Farm in Rodrigues and Pereira (15) are significantly higher at all scenarios of DIS due to rather remarkable precipitation occurrence and lower values of ET0 in their study area (Vigia Irrigation District, Evora District, Portugal) in summer cropping season. In wet water year, WPI-Farm was higher than two other water years (normal and drought) due to reduced IWU and with decreasing Ea values, this difference became lower. The difference between WPI-Farm obtained at different water years in Rodrigues and Pereira (15) is more visible because of humid climatic conditions of their study area with higher precipitation occurrence in summer cropping season.

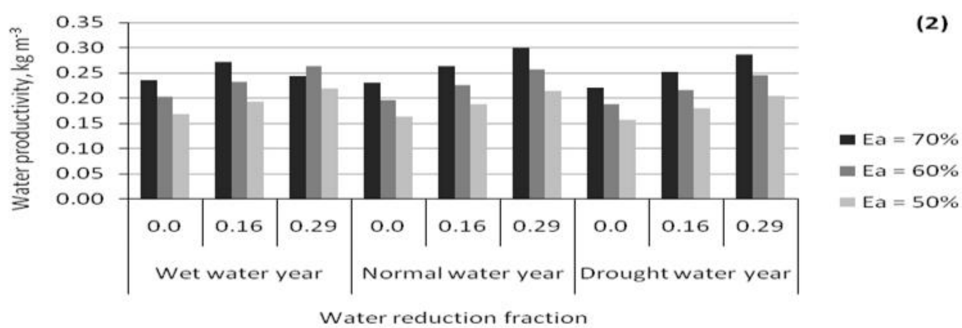
Rice

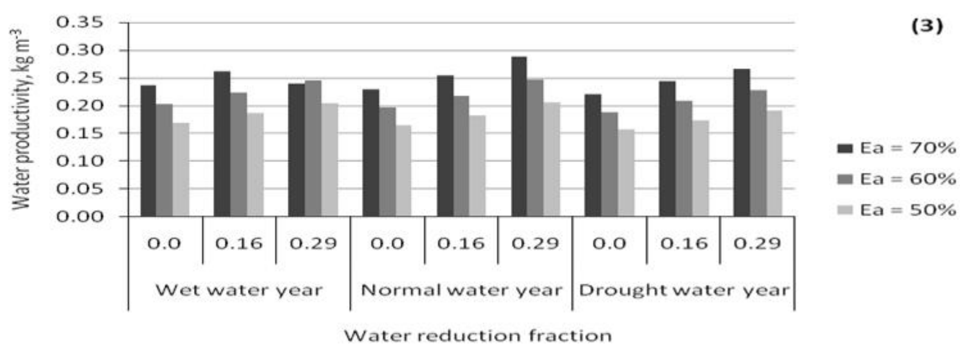
WPI-Farm for growing season of different water years, WRF, Ea values and methods of DIS was calculated for rice and the results for Ea= 50%, 60% and 70% are shown in Fig. 2 [values of WRF are 0.0, 0.16 and 0.29 that are related to continuous flooding, intermittent flood irrigation (1-day interval), intermittent flood irrigation (2-day interval), respectively]. With rising WRF, WPI-Farm increased for all experimental water years, Ea values and DIS methods with the exception of wet water year and Ea= 70% that, WPI-Farm initially increased and then decreased for all DIS methods because of lower irrigation application depth in this case. Therefore, only for Ea= 70% in wet water year, the maximum value of WP I-Farm occurred at WRF of 0.16 and in other conditions, the maximum value of WP I-Farm occurred at WRF of 0.29. Furthermore, the values of WPI-Farm decreased from wet water year to drought water year for all conditions with the exception of Ea=70% and WRF=0.29 that the values of WPI-Farm increased and then decreased for all DIS methods. Meanwhile, in DIS methods with greater number of full irrigated stages of growth, the mentioned fluctuations became lower. Between different methods of DIS, the method 4 has the highest WPI-Farm because in this method, at three stages after establishment stage (tillering, heading and flowering stages) full irrigation was applied. These results were obtained due to very high sensitivity of rice to water deficit compared with maize (0.65 vs. 0.078-0.558); therefore, it should be irrigated at all sensitive stages of growth. According to Zwart and Bastiaanssen (18), the globally measured average WP value for rice is 1.09 that this value is significantly higher than those obtained in our study. This difference is due to arid climate of our study area (Doroodzan district) with no precipitation in summer growing season.

Economic water productivity

EWPI-Farm follows the variation of WPI-Farm, except that the differences among different variables are more apparent. The values of EWPI-Farm are 3929 and 17391 times WPI-Farm for maize and rice, respectively. This indicates that rice is economically more efficient (343% higher) compared with maize.







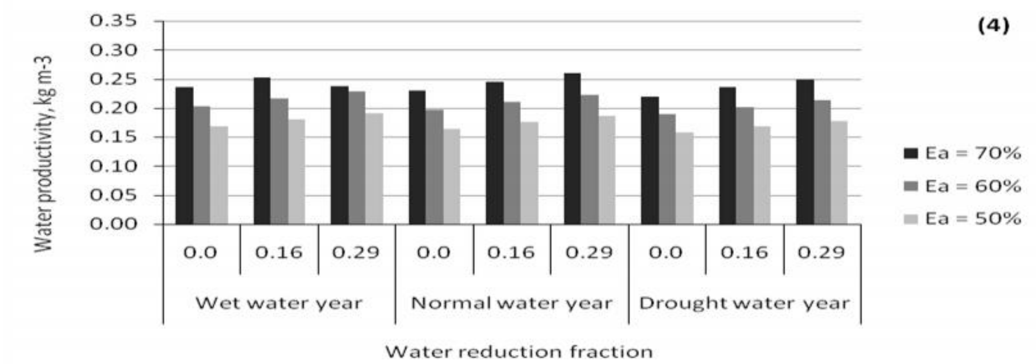


Fig. 2. Water productivity (WPI-Farm) of rice under different methods of deficit irrigation scheduling, water reduction fraction, different experimental water years and irrigation application efficiency (Ea): 1-4 are different methods of deficit irrigation scheduling

Assessment of water costs impacts under different irrigation systems

The economic water productivity ratio (EWPR) and net income (NI) earned per unit area (hectare) [EWPR1 and NI1 (considering the current cost of water) and EWPR2 and NI2 (considering the real cost of water)] was used to assess the impacts of water costs under different irrigation systems. These parameters were calculated for different crops, water years, WRF; Ea values (which are related to different irrigation systems) and methods of DIS. EWPR follow the same variation as for WPI-Farm and the values of EWPR1 are 46.77 and 199.89 times WPI-Farm for maize and rice, respectively and the values of EWPR2 are 3.42 and 15.12 times WPI-Farm for maize and rice, respectively. The obtained values of EWPR1 in Rodrigues and Pereira (15) are significantly lower than those obtained in our study because of higher current water cost in their research. Whereas, in spite of higher real water cost in Rodrigues and Pereira (15), the obtained values of EWPR2 in this study are lower than or equal to those obtained in our study because of lower irrigation depth.

Maize

For current cost of water and surface irrigation, solid-set sprinkler and tape irrigation systems (Ea=30-60%, 50-80% and 70-90%, respectively), water cost varied between 5-13.2%, 4.9-11.6% and 2.1-5.4% of total production cost, respectively. For surface and solid-set sprinkler irrigations, the NI1 was positive at all scenarios with exception of drought water year, Ea= 60% and DIS method of 1 and wet, normal and drought water year, Ea= 80%, WRF= 0.8 and DIS methods of 1 and 2, respectively. For these irrigation systems, NI1 increased with increasing Ea for DIS method of 4 for all conditions, because in this method, full irrigation was applied at stages of growth with higher sensitivity to water deficit (vegetative and flowering stages). For other methods, at WRF<=0.4 and WRF<=0.2, NI1 increased with increasing Ea in surface and solid-set sprinkler irrigation systems, respectively. However, for tape irrigation the NI1 obtained at WRF= 0.8 was negative for all Ea values and for Ea= 80% and 90%, the value of NI1 obtained for WRF=0.6 (in DIS method of 1) was negative. This was because of high sensitivity of maize to water deficit and higher fixed costs of tape irrigation system. In this irrigation system for all methods of DIS, the values of NI1 increased with increasing

Ea only for WRF=0.0 (full irrigation). Considering the real cost of water, for surface irrigation, solid-set sprinkler and tape irrigations, water cost varied between 43.9-68.5%, 39.7-63.2% and 21.2-42.6% of total production cost, respectively. For surface irrigation the NI2 was positive for all scenarios, with exception of WRF= 0.8 and by reducing the Ea values to 30% and from wet water year to drought water year, more negative values of NI2 were obtained. Therefore, the NI2 values obtained for Ea= 30% were negative at all conditions with exception of wet and normal water year, DIS methods of 1 and 2. In this irrigation system, for DIS methods of 1, NI2 increased with increasing Ea values at WRF<=0.4. For other methods of DIS, NI2 increased with increasing Ea values at all conditions, because in these methods, full irrigation was applied at stages of growth with higher sensitivity to water deficit (vegetative and flowering stages). This increase is more visible for DIS methods of 4 (vegetative and flowering stages fully irrigated). For solid-set sprinkler system the negative NI2 obtained for WRF=0.8 (DIS methods 1, 2, 3 in which deficit irrigation was applied at flowering stage). In this irrigation system, for DIS methods of 1 and 2, at WRF<=0.2 and WRF<=0.4, NI2 increased with increasing Ea values. In other DIS methods, NI2 increased with increasing Ea values at all conditions. For tape irrigation system the negative values are related to WRF= 0.4, 0.6 and 0.8 and by reducing Ea values and from wet to drought water year, number of cases with negative income increased. In this irrigation system, only for DIS method of 4, NI2 increased with increasing Ea values at all conditions. For DIS method of 2, at WRF<=0.4, NI2 increased with increasing Ea and for DIS method of 1, 3 and 5, only at WRF=0.0, NI2 increased with increasing Ea values. Comparison between our results and those of Popova and Pereira (12) indicated that application of deficit irrigation according to sensitivity of crop growth stages to water stress resulted in more water saving and higher net income.

Rice

For current cost of unit water, irrigation water cost varied between 4.1-11.2% of total production cost. For real cost of water, it varied between 36.2-63.4% of total production cost. The NI1 and NI2 values are positive for all scenarios and increased with increasing Ea with the exception of wet water year and WRF=0.29 that with increasing Ea to 60%, the NI1 and NI2 values increased and then decreased with increasing Ea to 70%. Meanwhile, the values of NI1 and NI2 increased with increasing WRF for all water years, Ea values and DIS methods. Despite the lower water consumption at method 1 of DIS and higher values of Ea and WRF that lead to minimum grain yield, the maximum values of NI1 and NI2 were obtained at these conditions (Ea=70% and WRF=0.16 for wet water year and Ea=70% and WRF=0.29 for normal and drought water year) because of high price of rice (17391 Rls kg-1). Results of EWPR1, EWPR2, NI1 and NI2 were not shown due to limitation in the article length.

CONCLUSIONS

This research showed the usefulness of WP as a tool to show the effects of different methods of water management in the field especially by considering economic aspects and showed the proficiency of deficit irrigation scheduling for farm water management at condition of water resources restrictions, especially by considering different growth stages of crops and irrigation systems.

For maize, the maximum value of WPI-Farm, EWPI-Farm and EWPR occurred at lower WRF. Maximum values of these parameters obtained for Ea= 90% occurred at WRF= 0.2. By increasing WRF, WPI-Farm values initially increased and then decreased for all Ea values and different methods of DIS. At lower values of Ea, the maximum value of WPI-Farm was obtained at higher WRF. These fluctuations at methods 4 and 5 of DIS were lower than other methods of DIS. Between different DIS methods, the maximum value of WPI-Farm obtained at method 2.

For rice, with increasing WRF the values of WPI-Farm, EWPI-Farm and EWPR increased for all conditions with the exception of Ea=70% and wet water year. In these cases, the values of WPI-Farm, EWPI-Farm and EWPR initially increased to a maximum and then decreased. The values of WPI-Farm, EWPI-Farm and EWPR at DIS methods in which higher sensitive stages were fully irrigated are close to each other.

Scenarios, in which the real cost of water was considered, showed considerably lower EWPR values that indicated the more importance of deficit irrigation in situation with real cost of water for gain more profit per cubic meter of water. Results showed that by considering current cost of water, the NI was positive in surface irrigation for all crops and conditions. By applying solid-set sprinkler and tape irrigation, this parameter was positive for maize at all conditions for WRF<=0.6 and WRF<= 0.4, respectively. By considering real cost of water, by reducing Ea and increasing seasonal crop evapotranspiration more cases resulted in negative income for maize at all irrigation systems. For rice, all cases resulted in positive incomes and the maximum values of NI obtained at DIS method of 1 and higher values of Ea and WRF. This indicated a good capability of this crop for application of deficit irrigation despite the high sensitivity of rice to water deficit. However, this might be different if the λi values were considered different for various growth stages.

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بررسی بهره وری آب به منظور مدیریت آب در مزرعه در شرایط مختلف دسترسی به آب برای گیاهان زراعی غالب تابستانه

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چکیده– استفاده کارآمد از آب آبیاری برای گیاهان زراعی تابستانه به دلیل عدم وقوع بارش در تابستان باید به طور جدی مورد بررسی قرار گیرد. این تحقیق کارایی مصرف آب را از طریق بررسی عامل بهره وری آب برای گیاهان زراعی تابستانه غالب در منطقه مورد مطالعه (ذرت و برنج) با در نظر گرفتن سناریوهای مختلف مدیریت آب در مزرعه تحت شرایط مختلف آب و هوایی مورد ملاحظه قرار داد. نتایج این تحقیق نشان داد که در اکثر موارد حداکثر بهره وری آب در سناریو آبیاری کامل اتفاق نمی افتد. با افزایش بازده کاربرد آب در مزرعه، بهره وری آب افزایش یافت و حداکثر بهره وری آب در کسر کاهش آب بالاتری رخ داد. برای ذرت در روش هایی از برنامه بندی کم آبیاری که در آنها در مرحله گلدهی آبیاری کامل انجام شده بود کاهش بیشتر آب از نظر اقتصادی قابل قبول بود. برای برنج با افزایش بازده کاربرد آب و کسر کاهش آب، بهره وری آب افزایش یافت و کم آبیاری در مراحل مختلف رشد از نظر اقتصادی توجیه پذیر بود. با در نظر گرفتن قیمت واقعی آب، نسبت بهره وری اقتصادی آب تا حد زیادی کاهش یافت به طوری که برای داشتن درآمد خالص مثبت در سیستم آبیاری سطحی باید بازده کاربرد آب در مزرعه افزایش می یافت و از اعمال کسرهای زیاد کاهش آب (بیشتر از ۰/۴) اجتناب می شد. در سیستم آبیاری بارانی، با افزایش بازده کاربرد آب در مزرعه نسبت بهره وری اقتصادی آب افزایش یافت و اعمال کسرهای کاهش آب بیشتر از ۰/۲ (۰/۲ تا ۰/۶ برای ذرت) قابل قبول بود. اعمال آبیاری قطره ای برای ذرت فقط برای کسرهای کاهش آب کمتر از ۰/۲ پذیرفتنی بود که با کاهش بازده کاربرد آب در مزرعه، کسرهای کاهش آب ۰/۲ تا ۰/۴ نیز از نظر اقتصادی توجیه پذیر بود.

واژه های کلیدی: زمین برنامه بندی کم آبیاری، بهره وری اقتصادی آب، بازده کاربرد آب در مزرعه، درآمد خالص، قیمت آب

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