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Does Deficit Irrigation Affect the Relation between Radiation Interception and Water Consumption for Durum Wheat (Triticum Durum Desf)?

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Abstract

Total Dray Matter (TDM), Photosynthetically Active Radiation Intercepted (PARabs), Water Consumption (WC), Water use- (WUE), Radiation use efficiency (RUE) and the relationship between Radiation Interception and Water Consumption for Durum Wheat were investigate under different irrigation amount (D_1= 100 % ETc; D_2= 70 % ETc; D_3= 40 % ETc and D_4= pluvial) and during three growing seasons (2005-2006, 2006-2007 and 2007-2008). Results showed that, the cumulative PAR abs decreased with deficit irrigation. In fact, D_1 treatment recorded the highest cumulative PAR abs and the lowest marked underD_4 treatment. Similarly, TDM and RUE were decreased with deficit irrigation. The highest RUE observed under the D_1 (from 1.32 to 1.43 g MJ^{-1}) and the lowest under D_4 (from 1.17 to 1.29 g MJ^{-1}). However WUE increased with deficit irrigation. The highest WUE were obtained under the D_4 (from 3 to 4 kg m^{-3}) and the lowest were observed under D_1 (from 2.8 to 3.1 kg m^{-3}). Significant linear relationship was found between cumulative PAR abs and cumulative water consumption with a high correlation coefficient (R^2) only under the two treatments D_1 and D_2.

Keywords: Durum wheat, total dry matter, water consumption, light interception, water and radiation use efficiency

1. Introduction

A cereal, especially Durum wheat (*Durum Triticum* L.) is one of the strategic crops in Tunisia. Durum wheat is cultivated mainly in semi-arid region of Tunisia. In fact, wheat production in this region is subject to the annual and monthly variability of rainfall. Also, the water scarcity and the uneven distribution of precipitation across time and space are a very serious problem especially in recent years due to climate change. Therefore, supplemental irrigation imposed for increasing crop yields and decrease water use (Aase and Pikul, 2000; Blum *et al*., 1991; Blum and Johnson, 1993; Li *et al*., 2001; Jiusheng, 1998; Katerji *et al*., 1998; Recio *et al*., 1999). However, in many case the management of irrigation by farmers using soil water balance is difficult. So, research of simple tools for the management of irrigation by farmer is a challenge. Therefore, the study of the relationship between water consumption and some physiological parameter is one of the methods used for research simple tools for irrigation management. In this context, several researches were made. Previous studies on energy balance made by Ritchie (1972), which introduced the energy balance approach to estimate evapotranspiration and transpiration separately for a canopy with incomplete cover. Tanner and Jury (1976) used forms of the Priestley–Taylor equation (1972) to obtain separate estimates of evapotranspiration and transpiration based on the amount of Rn-G above and below a potato (*Solanum tuberosum* L.) canopy. Concerning the relationships between radiation interception and some agro-physiological parameters, Monteith, (1972; 1977) recorded that dry matter production has often been found to be linearly related to the photosynthetically active radiation (PAR) absorbed or intercepted by crops. Calera-Belmonte et al. (2003) were studied the crop water by crop use in real time for individual fields on a regional scale using the relationship between crop light interception and basal crop coefficient (Kcb), allow efficient estimation of crop water use where reference ETo is available. Also Johnson et al., (2000) and Williams et al., (2005) showed that the basal crop coefficient for grape vines and fruit trees are closely related to mid-day light interception. Stöckle et al.,

(2003) recorded that transpiration is related to the amount of radiation intercepted by the canopy and soil evaporation is separated from the transpiration by using the fraction of intercepted radiation as a multiplier coefficient of maximum evapotranspiration (ETc, max). Suay et al., (2003), concluded that the fraction of crop intercepted radiation (F_{IR}) is a major determinant of Kc. Other researchers showed that the radiation intercepted represents the energy that can be absorbed by the canopy of plant and therefore be used for transpiration and it has been assumed that the relationship between absorbed energy and transpiration does not change throughout the season (Pereira et al., 2007). These results are confirmed by the researches in lysimeters on peach in California, reporting that noon intercepted radiation produced a significant linear relationship with Kc (Ayars *et al*., 2003; Johnson *et al*., 2005). Pereira et al. (2007) observed a linear relationship between daily canopy transpiration (Td) and daily net (all-wave) radiation multiplied by LAI for apple, olive and walnut. However, Girona et al. (2011) have found non-linear relationships between the fractions of midday intercepted PAR and crop relative water consumption across years. The non-linearity was attributed, in part, to the prevailing shape of apple canopies in hedgerows. Similarly, Auzmendi et al (2011) found that under full irrigation and during the pre-harvest period, a significant linear relationship observed between transpiration and radiation interception. Contrary, in the post-harvest period, this relationship was not significant, probably due to the reduced range of variation in transpiration and radiation interception. Accordingly, it seems interesting to investigate the responses of Durum wheat to different levels of supplemental irrigation and to study the relationships between water consumption and radiation interception (PARabs). So, the aims of our research were to investigate the effects of different irrigation levels on total dry matter production (TDM), photosynthetically active radiation intercepted (PARabs), water consumption (WC), radiation-, water use efficiency and to study the relationships between water consumption and radiation interception.

2. Materials and Methods

2.1 Experimental Site Characterization

The experiments were conducted in Bourbiaa region in Tunisia (36° 37’ N, 10° 08’ 25” E) during three cropping seasons (2005-2006, 2006-2007 and 2007-2008). The target region is characterized by semi-arid climate with 400 mm of the average annual rainfall. The soil had a clay texture with 180 mm m^{-1} total available water and 1.8 g l^{-1} water salinity. The Soil Organic Matter content (SOM %) in the surface layer is 1.22 and 0.75 in the depth. The bulk density varies from 1.25 to 1.55 from the surface layer to the depth (M’hamed *et al*., 2014).

2.2Plant Material

One variety of Durum wheat “*Triticum durum* Desf”, (Karim) was tested. The sowing density was 350 grains m^{-1} for the three cropping seasons (2005-2006, 2006-2007 and 2007-2008). The sowing was made with a drill on November 24th, November 31th and November 17th, respectively for 2006, 2007 and 2008.

2.3Experimental Design

The experimental design was Randomize Complete Blocking Design (RCBD) with 3 replications. Four treatments were tested (D_1: Full irrigated with 100% ETc, D_2: Deficit irrigation based on 70 % ETc, D_3: Deficit irrigation based on 40 % ETc and D_4: Rainfed). 150 kg nitrogenha^{-1} was applied at three phonological stages (30 % at 3 leafs stage, 40 % at tillering stage and 30 % at booting stage). Eight meters interval band was maintained between the water regimes treatments.

2.4Measurement Parameters

2.4.1Meteorological Data

Climate data were collected daily by an automatic agro-meteorological station. Collected data were minimum and maximum temperatures (Tmin and Tmax), minimum and maximum air relative humidity’s (HRmin and HRmax), wind speed (V) and rainfall (P) during the three growing seasons (2005/2006; 2006/2007 and 2007/2008). Reference evapotranspiration (ET_0) and solar radiation “MJ m^{-2} d^{-1}“(Rs) were estimated by the CROPWAT software (FAO, version 8) using the FAO-Penman-Monteith approach (Allen et al., 1998). The daily Rs were used to calculate the daily photosynthetically active radiation incident (PAR_0 = RS/2) (Monteith &Unsworth, 1990).

2.4.2 Estimation of the Daily Photosynthetically Active Radiation Intercepted

Estimates of daily fractional radiation interception (F) were made using (Equation. 1), the exponential equation as suggested by Monteith and Elston (1983). The extinction coefficient, k, was taken as 0.45 (Jamieson *et al*., 1995). Estimates of k generally range from 0.4 to 0.6 in cereals (Versteeg and van Keulen, 1986). Daily estimates of F were interpolated from measures of LAI in each treatment.

$$\mathrm{Fi} = 1 - \mathrm{e}^{(-\mathrm{K} * \mathrm{LAI})} \quad (1)$$

Photosynthetically active radiation intercepted by wheat (PARabs) was calculated using the formula of Beer (Manrique *et al*., 1991):

$$\mathrm{PARabs} = \mathrm{PAR0} * \mathrm{Fi} \quad (2)$$

PAR_0 is photosynthetically active radiation incident, which is equal to half of the solar radiation (Monteith &Unsworth, 1990).

2.4.3 Estimation of the Daily Water Consumption

The soil moisture content in the planting zone was measured monthly with gravimetrically method. Soil water content data were collected for every 15 cm interval in soil depth. After irrigation and precipitation, additional measurements were performed. Daily water consumption of wheat was calculated using the following equation (Li *et al*., 2010):

$$\mathrm{Wc} = \mathrm{P} + \mathrm{I} + \mathrm{U} + \mathrm{R} - \mathrm{D} - \mathrm{SW}(3)$$

where Wc (mm) is the water consumption; P (mm), precipitation; I (mm), irrigation water; R (mm), the surface runoff, which was assumed as not significant since concrete slabs were placed around each plot; D (mm), the downward flux below the crop root zone, which was ignored since soil moisture measurements indicated that drainage at the site was negligible; and SW, the change in water storage in the soil profile exploited by crop roots.

2.4.4 Conversion Efficiency of Photosynthetically active radiation intercepted into Dry Matter Production (RUE)

The RUE of wheat was calculated as follows (Rezig *et al*., 2013a):

$$\mathrm{RUE} = \frac{\mathrm{TDM}}{\mathrm{PARabs}} \quad (4)$$

Where RUE (kg m^{-3}) is the radiation-use efficiency for total dry matter production; TDM (g m^{-2}) is total dry matter production; and PARabs (MJ m^{-2}) is the cumulative photosynthetically active radiation intercepted over the wheat growing season.

2.4.5 Conversion Efficiency of Water Consumption into Dry Matter Production (WUE)

The WUE of wheat was calculated as follows (Rezig *et al*., 2013b):

$$\mathrm{WUE} = \frac{\mathrm{TDM}}{\mathrm{wc}} \quad (5)$$

Where WUE (kg m^{-3}) is the water-use efficiency for total dry matter production; TDM (g m^{-2}) is total dry matter production; and WC (mm) is the cumulative water consumption over the wheat growing season.

2.5 Statistical Analysis

An analysis of variance for all measured parameters was made, using Statistical Analysis System software (SAS, 1985). The variance analysis was completed by "*multiple comparisons of means*" with *Newman Keuls* test. Treatment means that the significant effects were separated by the test Least Significant Difference (LSD) at probability level of 5% (Little and Hill, 1978).

3. Results

3.1Impact of Irrigation Regimes in Total Dry Matter (TDM),Photosynthetically Active Radiation Intercepted (PARabs) and Radiation Use Efficiency (RUE)

The impact of deficit irrigation (D_1, D_2, D_3 and D_4) in total dry matter production (TDM); photosynthetically active radiation intercepted (PARabs) and radiation use efficiency (RUE) of Durum wheat at harvest and during the three experiments (2006, 2007 and 2008) were given in table 1. From these outcomes, we observed that the total dry matter production (TDM) decreased with deficit irrigation from D_1 to D_4.The uppermost TDM was achieved in the second experiment with the treatment D_1 (1487 g m^{-2}), afterward in the second treatment D_2 (1401.2 g m^{-2}). Nevertheless, the lowly was illustrated in the first experiment with D_4 treatment (1025.1g m^{-2}). Statistical analysis showed that the irrigation dose significantly affected ($P < 0.05$) the TDM at wheat harvest (results with more details in the previous article M'hamed *et al*., 2014).

In the same way, we observed that the (PARabs)decreased with deficit irrigation. In fact, the highestamount of PAR abs was observedin the second experiment under treatment D_1 (1041.5MJ m^{-2}) next toD_2 (1025.1MJ m^{-2}). So far, the smallest amountwas recorded in the D_4 treatment (907.3 MJ m^{-2}).In the first and second experiments

ANOVA analysis showed that there was no significant effect ($P > 0.05$) of irrigation dose on PAR abs between treatments D_1 and D_2. However, it was significant effect ($P < 0.05$) if comparedthem to(D_3 and D_4) treatments.

TheRUEwas the highest in D_1 and the lowest in D_4 treatment.As result, for the three experiments the RUE in D_1 has illustrated respectively an improved of (2.9; 7 and 2.3 %) and (5.1; 11.2 and 11.4 %) compared to D_3 and D_4.In fact, during the first and third experiments variance analysis showed that there was no significant effect (P > 0.05) of irrigation dose on RUE between treatments D_1 and D_2. Nevertheless, ANOVA analysis showed for the three experiments that there was significant effect ($P < 0.05$) if compared $D_1$to D_4 treatments.

Table 1.Radiation use efficiency at harvest (RUE) for the three wheat growing seasons and under the four irrigation treatments

	Cropping season								
	2005-2006			2006-2007			2007-2008		
	TDM	PARabs	RUE	TDM	PARabs	RUE	TDM	PARabs	RUE
D_1	1254.6 a	920.2 a	1.36 a	1487.0 a	1041.5 a	1.43 a	1362.2 a	1031.3 a	1.32 ab
D_2	1191.5 b	906.6 a	1.31 a	1401.2 b	1025.1 a	1.37 b	1322.2 a	964.0 b	1.37 a
D_3	1108.4 c	842.5 b	1.32 a	1262.4 c	948.5 b	1.33 b	1203.1 b	932.3 b	1.29 b
D_4	1025.1 d	794.5 c	1.29 b	1150.0 d	907.3 c	1.27 c	1100.7 c	940.5 b	1.17 c
LSD (5%)	53	41.6	0.067	39.3	32.1	0.045	52.6	43.6	0.065

TDM: Total dry matter at wheat harvest (g m^{-2}); PARabs: photosynthetically active radiation intercepted at wheat harvest (MJ m^{-2}); RUE: radiation use efficiency at wheat harvest (g MJ^{-1}); LSD: Least significant difference at 5 %.

3.2 Impact of Irrigation Regimes in Water Consumption (WC) and Water Use Efficiency (WUE)

The water consumption (WC) and the water use efficiency (WUE) of Durum wheat at harvest for the three experiments (2006-2007 and 2008) and under the four irrigation doses (D1, D2, D3 and D4) were given in Table 2. From these consequences, we observed that the total water consumption decreased significantly ($P < 0.05$) with deficit irrigation (D_2, D_3 and D_4). For more details, we noted during the three experiments (2006-2007 and 2008) that the greatestWC was marked under D_1treatment (445.1, 485 and 482 mm) followed by D_2 (407.9, 409.5 and 448 mm) and D3 (369.6, 357.2 and 411.3). However, the lowest was recorded in the D_4 treatment (289.8, 287 and 369.2 mm). In fact, for the three experiments the water consumption in D_1 has recorded respectively an increased of (8.4; 15.6and 7.1 %), (16.9; 26.3 and 14.7 %) and (34.9; 40.8 and 23.4 %) compared to D_2, D_3 and D_4. Similarly, the cumulative WC in D_2 has registered respectively an improved of (9.4; 12.8 and 8.2 %) and (28.9; 29.9 and 17.6 %) compared to D_3 and D_4.

Conversely, for radiation use efficiency, we observed during the three experiments (2006, 2007 and 2008) that the upmost WUE was found respectively under D_4 treatment (3.5, 4 and 3 kg m^{-3}) after that by D_3(3, 3.5 and 2.9 kg m^{-3}). However, the least was recorded respectively in the D_1 treatment (2.8, 3.1 and 2.8 kg m^{-3}).In detail, for the three experiments the water use efficiency in D_4 has illustrated respectively an increased of (14.3; 12.5 and 3.4 %), (17.4; 15 and 0 %) and (20; 22.5 and 6.7 %) compared to D_3, D_2 and D_1. From these results, we observed that the improvement of WUE in D_4 compared to the other treatments (D_3, D_2 and D_1) was the lowest in the third experiment. Statistical analysis showed that the WUE was significantly ($P< 0.05$) affected by irrigation doses (D_1, D_2, D_3 and D_4) for three experiments (2006, 2007 and 2008) (Table 2). Nevertheless, ANOVA analysis showed no significant difference ($P> 0.05$) observed between D_1, D_2 and D_3 treatments in the first experiment and respectively between (D_2 and D_3) and (D_3 and D_1) in the second and third experiments.

Table 2. Water use efficiency (WUE) at harvest for the three wheat growing seasons and under the four irrigation treatments

	Cropping season								
	2005-2006			2006-2007			2007-2008		
	TDM	WC	WUE	TDM	WC	WUE	TDM	WC	WUE
D_1	1254.6 a	445.1 a	2.8 b	1487.0 a	485.0 a	3.1 c	1362.2 a	482.0 a	2.8 b
D_2	1191.5 b	407.9 b	2.9 b	1401.2 b	409.5 b	3.4 b	1322.2 a	448.0 b	3.0 a
D_3	1108.4 c	369.6 c	3.0 b	1262.4 c	357.2 c	3.5 b	1203.1 b	411.3 c	2.9 b
D_4	1025.1 d	289.8 d	3.5 a	1150.0 d	287.0 d	4.0 a	1100.7 c	369.2 d	3.0 a
LSD (5%)	53	20	0.22	39.3	23	0.15	52.6	21	0.11

TDM: Total dry matter at wheat harvest (g m^{-2}); WC: cumulative water consumption at wheat harvest (mm);

WUE: water use efficiency at wheat harvest (Kg m^{-3}); LSD: Least significant difference at 5 %.

3.3 Relation between Photosynthetically Active Radiation Intercepted and Water Consumption

The impact of irrigation doses (D_1, D_2, D_3 and D_4) in the relationship between the photosynthetically active radiation intercepted (PARabs) and the water consumption (WC) of Durum wheat for the three experiments were given in Figure 1.

From these results, we observed during the three experiments and independently of the irrigation dose (D_1, D_2, D_3 and D_4), the cumulative PAR abs linearly increases with cumulative water consumption. Similarly, it was illustrated for the first and second experiments, that the slope of these curves was respectively the greatest under D_1[0.502 10^{-3} m^3 MJ^{-1}(R^2=0.978, n=6) and 0.457 10^{-3} m^3 MJ^{-1}(R^2=0.993, n=7)] and respectively the lowest under D_4 [0.419 10^{-3} m^3 MJ^{-1}(R^2=0.824, n=6) and 0.339 10^{-3} m^3 MJ^{-1} (R^2=0.981, n=7)].

In the same way, the relationship between the two concepts for each irrigation doses (D_1, D_2, D_3 and D_4) during the all three experiments was shown in Figure 2. From these outcomes, we observed clearly that the photosynthetically active radiation intercepted (PARabs) was closely related to the water consumption means significant linear regression mainly in two treatments D_1[0.48810^{-3} m^3 MJ^{-1} (R^2 = 0.989, n = 20)] and D_2 [0.48110^{-3} m^3 MJ^{-1} (R^2 = 0.978, n = 20)]. For the two treatments D_3 and D_4, when the deficit irrigation was more harsh although photosynthetically active radiation intercepted (PARabs) increased linearly with the water consumption (WC) but the correlation between the two concepts was less significant. In fact, the slopes of this curves was equal respectively to [0.45310^{-3} m^3 MJ^{-1} (R^2 = 0.936, n = 20)] and [0.40410^{-3} m^3 MJ^{-1} (R^2 = 0.861, n = 20)] for D3 and D_4.The results obtained in Figure 3 confirmed the previous analysis (Figure 1 and 2). In more details, if we analyses the relationship between the cumulative photosynthetically active radiation intercepted (PARabs) and the cumulative water consumption in all irrigation doses (D_1, D_2, D_3 and D_4) for each experiments (2006, 2007 and 2008), we observed that the correlation between the two concepts was less significant respectively in the first[0.47810^{-3} m^3 MJ^{-1} (R^2 = 0.921, n = 24)] and second experiment[0.41510^{-3} m^3 MJ^{-1} (R^2 = 0.950, n = 28)] than that in the third experiment [0.49010^{-3} m^3 MJ^{-1} (R^2 = 0.982, n = 28)]. In specify, the impact of irrigation doses was more important in the first and second experiment than that in third experiment. In upshot we noted that deficit irrigation between (D_1 and D_3) and (D_1 and D_4) and during the three experiments (2006, 2007 and 2008) were respectively equal to (75 and 155 mm), (128 and 198 mm) and (70 and 112 mm). Taken all together, we can conclude that deficit irrigation presented an imperative consequence in the relationship between PAR abs and water consumption.

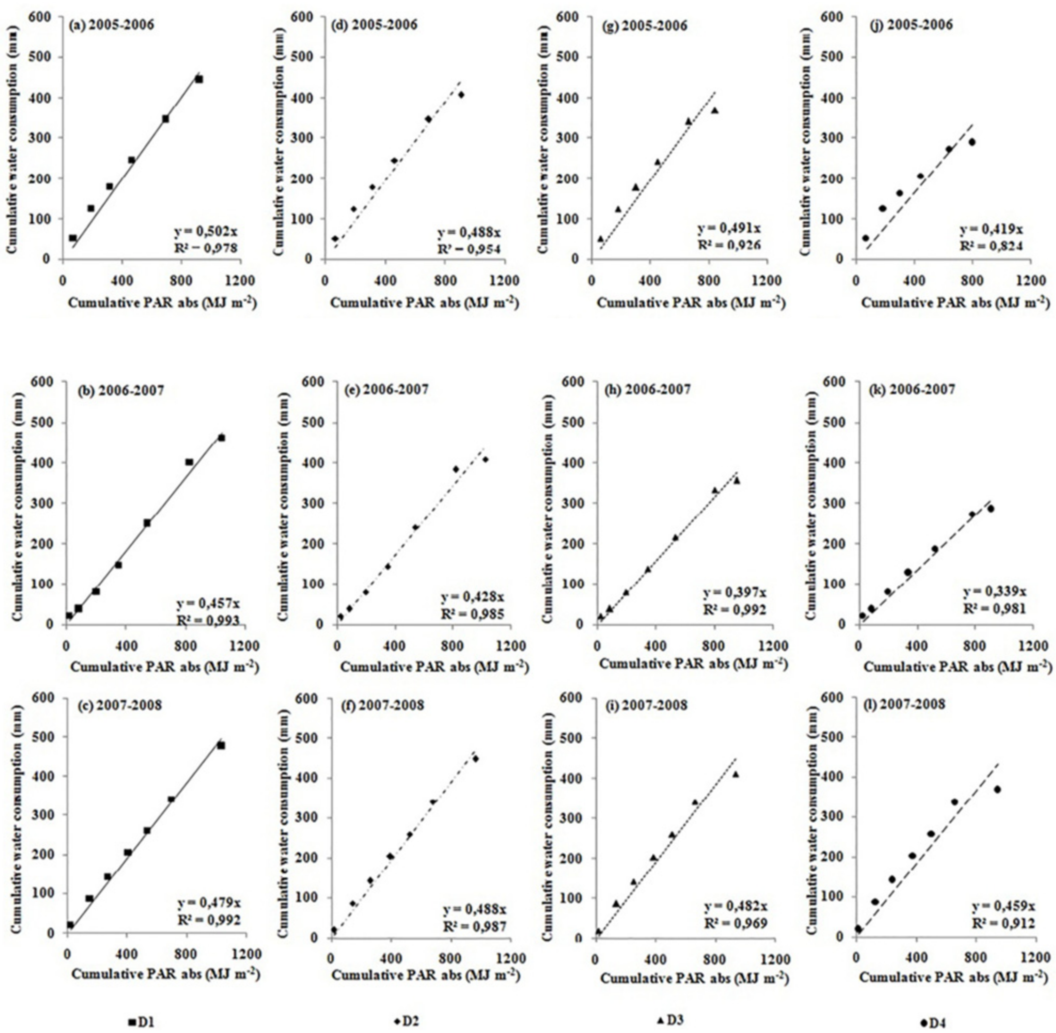

Figure1.Relationship between cumulative photosynthetically active radiation intercepted (MJ m^{-2}) and cumulative water consumption (mm) during the three growing seasons from 2005 to 2008 and under four irrigation dosesD_1 (a, b and c); D_2(d, e and f); in D_3 (g, h and i) and in D_4(j, k and l).

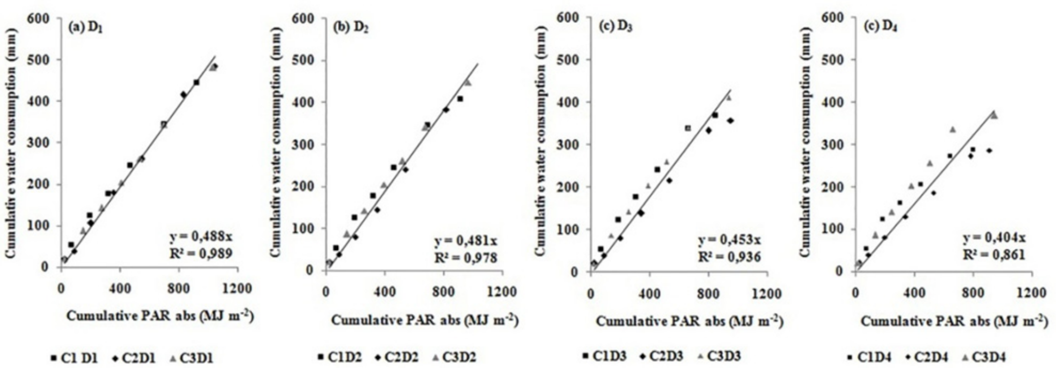

Figure2. Relationship between cumulative photosynthetically active radiation intercepted (MJ m-2) and cumulative water consumption (mm) during the three growing seasons and under four irrigation dosesD1 (a); D2(b); D3 (c) andD4(d)

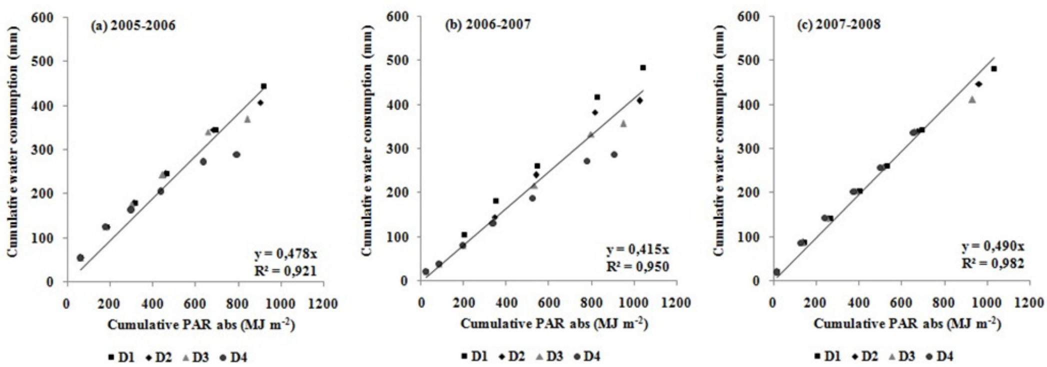

Figure3.Relationship between cumulative photosynthetically active radiation intercepted (MJ m^{-2}) and cumulative water consumption (mm) for the four irrigations doses (D_1, D_2, D_3 and D_4) and during the three experiments 2005-2006 (a), 2006-2007 (b) and 2007-2008 (c)

3.4 Discussion

Deficit irrigation during the reproductive crop growing season is the first limiting factor for cereals (Blum, 2009). In order to evaluate the impact of deficit irrigation in the relationship between radiation interception and water consumption,the total dry matter production (TDM); the photosynthetically active radiation intercepted (PARabs); the water consumption (WC), the radiation- and water use efficiencies for dry matter were investigated under different irrigation levels (D_1, D_2, D_3 and D_4).

From results in table 1, we observed that the total dry matter production (TDM) decreased significantly ($P < 0.05$) with deficit irrigation. In detail, for the three experiments (2006, 2007 and 2008), the highest TDM was achievedrespectively in the treatment D_1 (1254.6, 1487, 1362.2 g m^{-2}) and the lowest was illustrated respectively in the treatment D_4 (1025.1, 1150, 1100.7 g m^{-2}). Statistical analysis showed that the deficit irrigation significantly affected ($P < 0.05$) the TDM. Likewise for the photosynthetically active radiation intercepted (PARabs), the control treatment D_1 (D_1 = 100 % ET_C = 445; 485 and 482 mm) has achieved respectively during the three experiments the uppermost PAR abs and the smallest was obtained respectively in treatments D_4 (D_4 = pluvial = 290; 287 and 369 mm). Our results showed clearly that under drought stress predominantly in the two treatments (D_3 = 40 % ETc and D_4= pluvial), TDM and PAR abs decreased significantly with deficit irrigation.This result was consistent with the findings of Tesfaye et al. (2006), they found that the dry matter production is linearly related to PAR interception and they reclaimed that the low TDM production in the MS treatment (Mid-season stress=Flowering/pod setting) is principally attributed to low PAR interception. In fact, irrigation is important factor for plant productivity which plays vital role in biomass accumulation, dry matter partitioning and grain development (Hasanuzzaman and Karim 2007; Hasanuzzaman *et al*., 2008).There is a linear relationship between cumulative-intercepted photosynthetically active radiation (PAR abs) and accumulated-biomass (Loomis and Williams, 1963; Monteith, 1972; 1977; Gallagher and Biscoe, 1978; Kiniry *et al*., 1989; Russell *et al*., 1989; Sinclair and Muchow, 1999; Ceotto and Castelli, 2002; Rezig *et al*., 2013a; 2013b; 2015). Therefore, determining RUE is an important approach for understanding crop growth and yield (Sinclair and Muchow, 1999).Results in table 1 showed that the radiation use efficiency (RUE) decreased with deficit irrigation. In fact, the RUE achieved the highest amount in D_1 and the lowest in D_4 treatment. These results are consistent with those ofXianshi et al., (1998) and Collinson et al (1999). They found that the deficit irrigation reduces the radiation interception owing to the foliage rolling and they affirmed that the number and size of leaves may be reduced or the total leaf area may decrease with extended deficit. Jamieson et al., (1995), showed that drought reduced transpiration by a combination of stomatal control and reduced radiation interception. Early drought (from emergence) caused changes in the radiation use efficiency and reduced the quantity of radiation intercepted. Unlikeness, drought initiated in the season accelerated leaf senescence and consequently reduced only radiation interception. Uhart and Andrade (1995) announced under the same condition that the reduction in the leaf photosynthetic rate could result in lower RUE.Drought stress to begin with affects leaf development but soon after results in a decrease in radiation use efficiency of intercepted light in CO_2 assimilation (Whitfield 1993).Similarly, several studies on grain legumes (e.g. Hughes and Keatinge, 1983; Muchow, 1985; Green *et al*., 1985; Singh and Sri Rama, 1989), reported the reductions in radiation use efficiencyunder water deficits. A significantly higher reduction of seed yield under drought stress in reproductive and vegetative growing season has also been mentioned in chickpea (Sivakumar and Singh, 1987), beans (Acosta Gallegos and Shibata, 1989) and cowpea (Turk *et al*., 1980). As analyses indicated, that deficit irrigation had significant effects on water consumption (Table 2). In fact, the highest amount of WC was obtained under the D_1, with reduced irrigation doses, WC also decreased and the lowest values were observed under D_4 treatments. Nevertheless, the water use efficiency (WUE) increased with deficit irrigation. In this circumstance, the highest WUE was registered under D_4 treatment. Thus, several water-saving methods have been developed (Belder *et al*., 2004; Bouman *et al*., 2006), surrounded by deficit irrigation and may possibly to improve agricultural water use. Our results are in agreement withthose of Rao and Bhardwaj (1981); Zhang et al (2001); Nasseri and fallahi, (2007) and Qiu et al., (2008). They observed under deficit irrigation and on applying irrigation at critical growth stages WUE increased. Likewise, many researchers announced that the variability in determining WUE, generally qualified to the water regime applied (Katerji *et al*., 2008 and Zwart and Bastiaanssen. 2004).Xue et al. (2006) showed that deficit irrigation of 100 mm at booting stage increased respectively yield and WUE by 46 and 23% as compared to irrigated treatment. Similarly, Oweis et al., (1998) found higher values of WUE particularly under deficit irrigation when irrigation is practical at the decisive stages of plant development.The same as when drought became more severe and water use declined; there was an increase in WUE (Peuke *et al*. 2006). Also, numerous studies on the effects of limited irrigation on crop yields and WUE showed that by reducing irrigation doses, crop yield could be maintained and product quality improved (Li., 1982;Zhang *et al*., 1998), and appropriate irrigation management increase WUE (Kang *et al*., 2002; Guo *et al*., 2008). However, Singh et al. (1991) declared that the impact of limited irrigation and soil water deficit on WUE depends on the crop growth stage. They showed that higher irrigation doses decreased WUE (Sun et al., 2006).

Figure 1 showed that during the three experiments (2006, 2007 and 2008), the cumulative PAR abs linearly increases with cumulative water consumption. Similarly, it was showed for the first and second experiments, that the slope of these curves was respectively the greatest under D_1 and the lowest under D_4. However, for the third experiment the highest slope was marked in D_2 and followed by D_3. In more detail, the difference in the water consumptionbetween (D_1 and D_2) and respectively between (D_1 and D_3) during the three experiments (2006, 2007 and 2008) were equal to (37.2; 75.5 and 34)and(75.5; 127.8 and 70.7 mm). In the same way the difference in the radiation interception during the three experiments (2006, 2007 and 2008) were respectively equivalent to (13.6; 16.4 and 67.3 MJ m^{-2}) between (D_1 and D_2) and equal to (77.7; 93 and 99 MJ m^{-2}) between (D_1 and D_3). From these outcomes, we observed clearly that the impact of deficit irrigation in water consumption for the two treatments D_2 and D_3 was the most important in the second experiment (2007). However, this impact in radiation interception was respectively the highest in the third experiment for $D_2$and in the second (2007) and in third experiment (2008) for D_3. From those analyses, it was be clear that the improving slopes in D_2 and D_3 compared as D_1during the third experiment found its basis from the important simultaneous reduction in water consumption and radiation interception.

Likewise, the relationship between the cumulative photosynthetically active radiation intercepted and cumulative water consumption in each treatment (D_1, D_2, D_3 and D_4) and during the all three experiments (Figure 2) showed clearly that the photosynthetically active radiation intercepted (PAR abs) was closely related to the water consumption means significant linear regression mainly in two treatments D_1 and D_2. For the two treatments D_3 and D_4, the correlation between the two concepts was less significant.

As analyses was confirmed means the results obtained in Figure 3. In fact, the relation between the cumulative photosynthetically active radiation intercepted (PAR abs) and the cumulative water consumption in all irrigation doses (D_1, D_2, D_3 and D_4) for each experiments (2006, 2007 and 2008), illustrated that the correlation between the two concepts was less significant respectively in the first and second experiment than that in the third experiment. In specify, the simultaneous impact of deficit irrigation in water consumption and radiation interception mainly in treatment D_4 (pluvial = without irrigation) was more important in the first and second experiment than that in third experiment. If we took the entire three hypotheses detailed in Figure 1, 2 and 3, it can conclude that deficit irrigation presented an imperative consequence in the relation between PAR abs and water consumption.Our results are in agreement with this of Sadras et al., (1991) and Caviglia and Sadras, (2001). The later authors found significant relations between radiation use efficiency and water use efficiency for sunflower and spring wheat. Similarly, Rezig et al., (2007); (2010) were illustrated significant linear relationship between water consumption and absorbed PAR accumulated for sole potato and for wheat under different nitrogen rates (Rezig et al., 2015). Likewise, Auzmendi et al (2011) was found that under full irrigation and during the pre-harvest period, a significant linear relationship between transpiration and radiation interception.

4. Conclusion

This studyfound that deficit irrigation affect significantly the total dry matter production (TDM), photosynthetically active radiation intercepted (PARabs), water consumption (WC), radiation use- (RUE), Water use efficiency (WUE) and the relation betweenradiation interception and water consumption of Durum Wheat (*Triticum durum* Desf). Results showed that, the cumulative PAR abs and water consumption decreased with deficit irrigation. In fact, D_1 treatment marked respectively the highest (PARabs and WC) and the lowest (PARabs and WC) were achieved under treatment (D_4 = without irrigation). Similarly, TDMand RUE decreased with increasing deficit irrigation. However, WUE increased with treatment D_4. Deficit irrigation affects significantly the linear correlation between PAR abs and WC. Significant linear relationship was found between cumulative PAR abs and cumulative water consumption with a high correlation coefficient (R^2) only under the two treatments D_1 (full irrigation= 100 % Etc) and D_2(70 % ETc).

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