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Durum Wheat (*Triticum durum* Desf): Relation between Photosynthetically Active Radiation Intercepted and Water Consumption under Different Nitrogen Rates

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Abstract

The effects of four nitrogen rates (N_1 = 150 kg N ha^{-1}; N_2 = 100 kg N ha^{-1}; N_3 = 50 kg N ha^{-1} and N_4 = 0 kg N ha^{-1}) on Total dry matter (TDM), photosynthetically active radiation intercepted (PARabs), Water Consumption (WC), Radiation use efficiency (RUE), Water use efficiency (WUE) and the relation between photosynthetically active radiation intercepted and water consumption for Durum Wheat were investigated during three growing seasons (2005-2006, 2006-2007 and 2007-2008). Results showed that, the cumulative PARabs increase with nitrogen levels. In fact, N_1 treatment recorded the highest cumulative PAR abs (920.2, 1041.5 and 1031.3 MJ m^{-2}) and the lowest (812.7, 999.4 and 954 MJ m^{-2}) obtained under N_4 treatment, respectively for three growing seasons. Also, RUE, TDM and WUE have increased with nitrogen rates. The highest RUE observed under the N_1 (from 1.32 to 1.43 g MJ^{-1}) and the lowest under N_4 (from 1.1 to 1.27 g MJ^{-1}). N_1 treatment improved the TDM compared to N_3 and N_4 rates, respectively from 11.7 to 12.6% and from 15 to 22.3%. The highest WUE were obtained under the N_1 (from 2.8 to 3.1 kg m^{-3}) and the lowest were observed under N_4 (from 2.4 to 3 kg m^{-3}). The relationship between cumulative PAR abs and cumulative water consumption was linearly regression with a high correlation coefficient (R^2) which indicates that cumulative PAR abs increases when water consumption increases.

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

1. Introduction

To understand how crop production and resource efficiency-coefficients reply to both optimum or limiting water and nutrient supplies, it is important to find out the best management practices in order to optimize mutually yields and resource use efficiencies. This perceptive can evaluate and improve future agricultural systems in order to increase yields and the efficiency of resource use (Kant et al., 2011; Mulvaney et al., 2009; Sadras & Angus, 2006). In non-stress environment, total above-ground biomass, dry-matter and yield are determined by the product of total solar radiation, the fraction of radiation interception by the crop canopy and the efficiency by which intercepted radiation is converted into biomass via photosynthesis (Monteith, 1972). Later, total biomass production is determined by the amount of cumulative photosynthetically active radiation intercepted and the radiation-use efficiency, RUE (Monteith, 1977). Gallagher and Biscoe (1978) first established the conformist nature of radiation-use efficiency (RUE) in crops with cereals. Recently, Abbate et al. (1997) demonstrated that intercepted photosynthetically active radiation (IPAR) was the main factor determining crop growth in wheat. However, in many production systems world-wide, yields are limited both by water and nitrogen accessibility. Under these circumstances, both radiation interception and radiation use efficiency can be reduced through stresses on canopy expansion and photosynthesis rates, respectively (Lemaire et al., 2008).

Nitrogen and water limitation affected biomass yield, the efficiencies of radiation, water and nitrogen use in maize crops (Teixeira et al., 2014). For wheat, a significant linear relationship between ε_W and ε_R indicated that the rate of transpiration per unit of intercepted radiation (i.e. crop conductance, gc, mm MJ^{-1}) was conformist across contrasting N availability (Caviglia & Sadras, 2001). Nevertheless, the negative response of RUE under nitrogen deficiency has been published for different crops (Sinclair & Muchow, 1999; Massignam et al., 2009;

Lemaire & Gastal, 2009). The RUE reductions have been related to changes in the specific leaf N (SLN; g N m^{-2} leaf) (Muchow & Davis, 1988; Sinclair & Horie, 1989; Muchow & Sinclair, 1994; Sinclair & Muchow, 1999). Increasing nitrogen application rates results in increased RUE as long as the specific leaf nitrogen stays under saturating N content (Fischer, 1993; Abbate et al., 1995; Sinclair & Muchow, 1999). However, reduced RUE values can come about at awfully high nitrogen rates (Garcia et al., 1988; Olesen et al., 2000). In Mediterranean type-environments, water and nitrogen often co-limit grain yield (Sadras, 2004; Cossani et al., 2009). Ejaz and Ahmad (2010) found that nitrogen application increased water use efficiency at all irrigation levels. In fact, the maximum values of WUE were recorded under the nitrogen treatment of 150 kg N ha^{-1} followed by 100, 50 and 0 kg N ha^{-1} treatments. Many researchers affirmed that restraint nitrogen rate reduced water use efficiency for maize (Teixeira et al., 2014) and for temperate cereals such as wheat and barley crops (Cabrera-Bosquet et al., 2007; Cooper et al., 1983). Strong linear relationship between radiation use efficiency and water use efficiency were reported for sunflower and spring wheat (Sadras et al., 1991; Caviglia & Sadras, 2001). Similar relationships between water consumption and absorbed PAR accumulated were found for sole potato (Rezig et al., 2007, 2010; Sahli et al., 2003) and intercropping system sulla potatoes (Rezig et al., 2007, 2010). Also, Auzmendi et al. (2011), found under full irrigation and during the pre-harvest period a significant linear relationship between daily canopy transpiration (T_d) and daily canopy intercepted photosynthetically active radiation (IPARd) for apple tree.

Likewise for maize, Teixeira et al. (2014) illustrated strong linear relationship between the use efficiencies of radiation interception and of transpired water. In fact, many studies have been carried out to investigate the relation between radiation interception and water consumption. However, any information regarding the impact of nitrogen rates on the relation between photosynthetically active radiation intercepted and water consumption for wheat has been reported. Therefore, the objective of this study was to investigate the effects of four nitrogen rates (N_1, N_2, N_3 and N_4) on the total dry matter production (TDM), photosynthetically active radiation intercepted (PARabs), radiation use efficiency (RUE), water consumption (WC), Water use efficiency (WUE), and the relation between photosynthetically active radiation intercepted and water consumption for Durum Wheat (*Triticum durum* Desf).

2. Materials and Methods

2.1 Climate, Site and Experimental Design

Field experiments were conducted in semi-arid climate at Agronomic Area, Private farm 'El Khir', Tunisia (36°37′N, 10°08′25″E), during three successive growing seasons from 2005 to 2008 in the midst of analysing the relation between photosynthetically active radiation intercepted and water consumption for Durum Wheat (*Triticum durum* Desf, cultivar Karim) under different nitrogen rates.

The mean annual rainfall is 400 mm, whereas the pan evaporation varies from 1.4 (January) to 8.1 mm day^{-1} (July). The average daily temperature is 10 °C in January and 28 °C in July. The soil is clay with 180 mm m^{-1} total available water and 1.8 g L^{-1} water salinity. The Soil Organic Matter content (SOM%) are 1.22, 0.9 and 0.75 respectively for 0-20 cm, 20-40 cm and 40-100 cm horizons. The pH of soil varies from 8.1 to 8.5 (M'hamed et al., 2014).

The experimental design was Randomize Complete Blocking Design (RCBD) with 3 replications. The experiment covered four treatments (N_1 = 150 kg N ha^{-1}; N_2 = 100 kg N ha^{-1}; N_3 = 50 kg N ha^{-1} and N_4 = 0 kg N ha^{-1}). Nitrogen applications were 30%, 40% and 30% respectively at 6 leafs phase, at tillering period and at stem elongation stage (M'hamed et al., 2014).

2.2 Meteorological Data, Leaf Area Index (LAI) and Total Dry Matter (TDM) Measurements

Climatic data: (1) Daily Minimum and Maximum Temperatures (Tmin and Tmax); (2) Daily Relative Humidity (HR); (3) Wind Speed (V) and (4) Rainfall (P) were registered during the three growing seasons from 2005 to 2008 by automatic agro-meteorological station. Reference evapotranspiration (ET_0) and solar radiation (Rs, MJ m^{-2} d^{-1}) were estimated by the software CROPWAT 8 using the FAO-Penman-Monteith approach (Allen et al., 1998).

The daily solar radiation (Rs) were used to calculate the daily photosynthetically active radiation incident ($PAR_0 = R_S/2$) (Monteith & Unsworth, 1990).

The observations of crop growth analysis were performed on Leaf Area Index (LAI) and total dry matter (TDM g m^{-2}). The wheat sampling was collected using one square meter. Details of the sampling times for each experiment are shown in Table 1. The measure of TDM was made using a precision balance (Sartorius, Model PB3001) after oven drying at 65 °C. Leaf area was measured using planimeter type CID Inc-Cl-202.

Table 1. wheat sampling times

Experiment	Year	Sampling Time (Days after Sowing)
Exp. 1	2005-2006	45, 70, 99, 118, 138, 164, 204
Exp. 2	2006-2007	45, 67, 92, 114, 134, 164, 198
Exp. 3	2007-2008	45, 83, 104, 124, 140, 160, 211

2.3 Theoretical Formulations

2.3.1 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 & van Keulen, 1986). Daily estimates of F were interpolated from measures of LAI in each treatment.

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

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

$$\mathrm{PARabs} = \mathrm{PAR0} * \mathrm{Fi} \tag{2}$$

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

2.3.2 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):

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

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.

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

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

$$\mathrm{RUE} = \frac{\mathrm{TDM}}{\mathrm{PARabs}} \tag{4}$$

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.

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

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

$$\mathrm{WUE} = \frac{\mathrm{TDM}}{\mathrm{wc}} \tag{5}$$

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

2.4 Statistical Analysis

Data collected were analyzed statistically by software (SAS, 1985) using Fisher's variance analysis. Differences among the treatments' means were compared using least significant difference (LSD) at 5% probability level (Steel et al., 1997).

3. Results

3.1 Conversion Efficiency of Photosynthetically Active Radiation Intercepted into Total Dry Matter Production (RUE)

Figure 1 and Table 2 revealed respectively the conversion efficiency of photosynthetically active radiation intercepted into total dry matter production over all Durum wheat growing season (RUE) and at Durum wheat harvest (RUE_F) for the three experiments and under the four treatments (N_1, N_2, N_3 and N_4).

From these results, we observed that the cumulative total dry matter production has a large variability, depending on wheat growing seasons and nitrogen level. The highest amount of TDM was observed in the treatment N_1 (from 1254.7 to 1487 g m^{-2}) followed by N_2 (from 1222.6 to 1454.1 g m^{-2}). However, the lowest was recorded in the N_4 treatment (from 1038.9 to 1264.1 g m^{-2}). Statistical analysis showed that the nitrogen rate significantly affected ($P < 0.05$) the TDM accumulation at wheat harvest (results with more details in the previous article M'hamed et al., 2014). Similarly, we noted that the cumulative photosynthetically active radiation intercepted (PARabs) increased with nitrogen application. In fact, the maximum quantity of PAR abs was registered under treatment N_1 (from 920.2 to 1041.5 MJ m^{-2}) followed by N_2 (from 885.6 to 1042.7 MJ m^{-2}). However, the minimum amount was recorded in the N_4 treatment (from 812.7 to 999.4 MJ m^{-2}). During the second and third experiments variance analysis showed that there was no significant effect ($P \geq 0.05$) of nitrogen application on cumulative PAR abs between treatments N_1 and N_2. Nevertheless, ANOVA analysis showed that there was significant effect ($P < 0.05$) if compared (N1 or N2) to (N_3 and N_4) treatments. Throughout the Durum wheat growing season (Figure 1) the conversion efficiency of cumulative photosynthetically active radiation intercepted (RUE) was more important in (N_1 and N_2) than that in (N_3 and N_4) treatments. Consequently, for the three experiments the RUE in N_1 has recorded respectively an increase of (6.6; 8.5 and 1.5%) and (10.2; 9.9 and 6.6%) compared to N_3 and N_4. Variance analysis showed that there was no significant effect ($P \geq 0.05$) of nitrogen application on RUE between treatments N_1 and N_2. However, ANOVA analysis showed that there was significant effect ($P < 0.05$) if compared (N1 or N2) to (N_3 and N_4) treatments. Likewise at wheat harvest (Table 2) the RUE_F was higher in (N_1 and N_2) than that in (N_3 and N_4) treatments. So, for the three experiments the RUE_F in N_1 and N_2 was respectively equal to [(1.36, 1.43 and 1.32 g MJ^{-1}) and (1.38, 1.39 and 1.31 g MJ^{-1})] and it was respectively equivalent to [(1.29, 1.30 and 1.24 g MJ^{-1}) and (1.27, 1.26 and 1.11 g MJ^{-1})] in N_3 and N_4. As a results, the nitrogen level N_1 has improved RUE_F during the three experiments from 2005 to 2008 respectively (from 5.1% to 9.1%) and (from 6.6 to 15.9%) next to in N_3 and N_4. Variance analysis showed that there was no significant effect ($P \geq 0.05$) between treatments N_1 and N_2 on RUE_F. Even so, ANOVA analysis showed that there was significant effect ($P < 0.05$) between N1 and N_4 treatments.

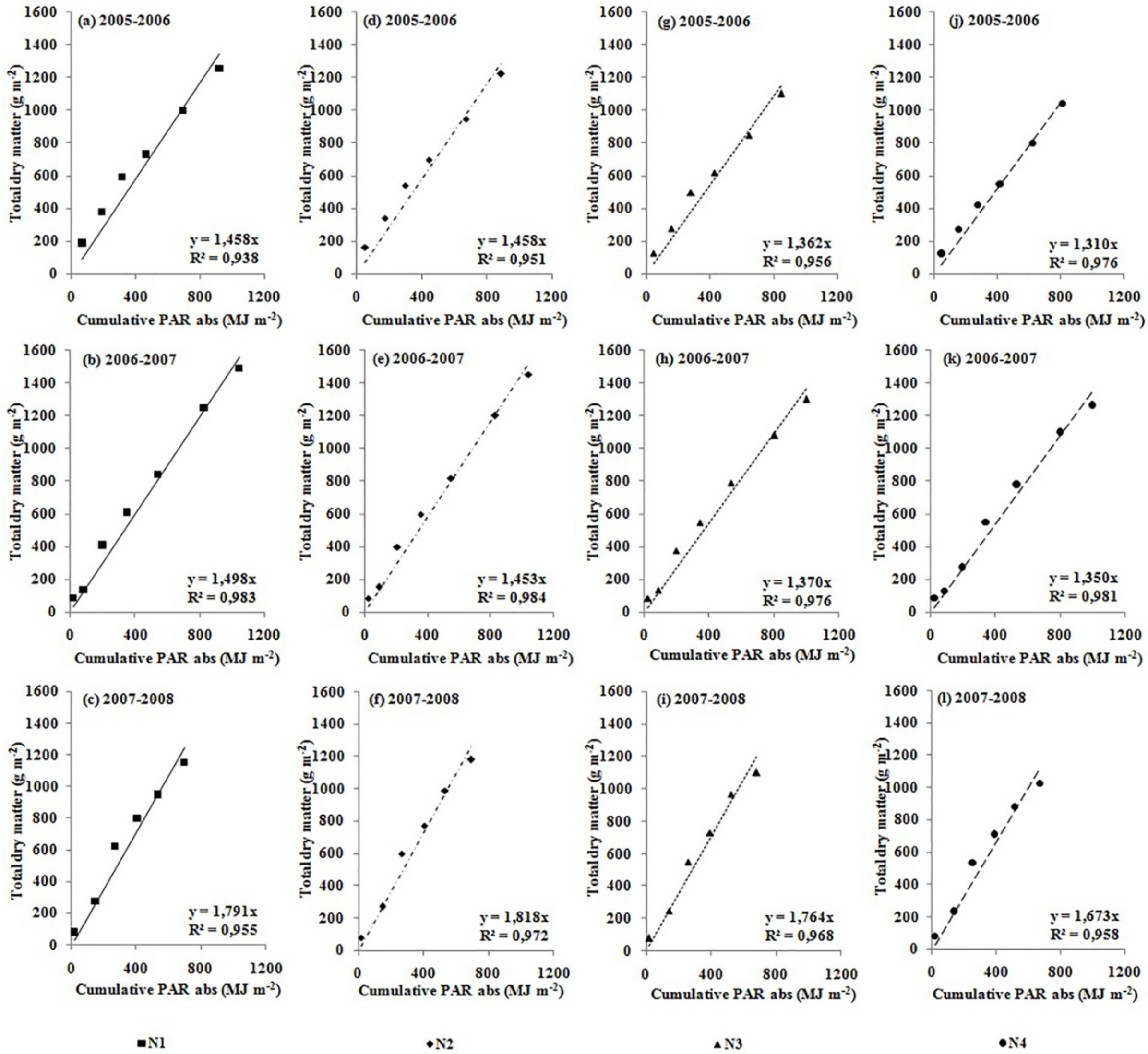

Figure 1. Relation between cumulative photosynthetically active radiation intercepted (MJ m^{-2}) and cumulative total dry matter production (g m^{-2}) during the three growing seasons from 2005 to 2008 and under four nitrogen amount N_1 (a, b and c); N_2 (d, e and f); in N_3 (g, h and i) and in N_4 (j, k and l)

Table 2. Conversion efficiency of photosynthetically active radiation intercepted into total dry matter production at harvest (RUE) for the three wheat growing seasons and under the four nitrogen treatments

Treatments	Cropping season								
	2005-2006			2006-2007			2007-2008		
	TDM_F	$PARabs_F$	RUE_F	TDM_F	$PARabs_F$	RUE_F	TDM_F	$PARabs_F$	RUE_F
N1	1254.6 a	920.2 a	1.36 ab	1487.0 a	1041.5 a	1.43 a	1362.0 a	1031.3 a	1.32 a
N2	1222.6 a	885.6 b	1.38 a	1454.1 a	1042.7 a	1.39 ab	1331.1 a	1013.9 a	1.31 a
N3	1100.3 b	847.6 c	1.29 ab	1300.1 b	997.4 b	1.3 ab	1203.1 b	966.0 b	1.24 a
N4	1038.9 c	812.7 d	1.27 b	1264.1 c	999.4 b	1.26 b	1058.7 c	954.0 b	1.11 b
LSD	**49.7**	**32.0**	**0.11**	**34.9**	**38.0**	**0.14**	**62.8**	**35.2**	**0.1**

Note. TDM_F: Total dry matter at wheat harvest (g m^{-2}); PARabs $_F$: photosynthetically active radiation intercepted at wheat harvest (MJ m^{-2}); RUE_F: Conversion efficiency of photosynthetically active radiation intercepted into total dry matter production at wheat harvest (g MJ^{-1}); LSD: Least significant difference at 5%.

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

The conversion efficiency of water consumption into total dry matter production over all Durum wheat growing season (WUE) and at Durum wheat harvest (WUE_F) for the three experiments and under the four treatments (N_1, N_2, N_3 and N_4) were given respectively in Figure 2 and Table 3.

From these results, we observed that the cumulative water consumption increased with nitrogen application. In fact, the maximum amount of WC was registered under N_1 treatment (from 445 to 485 mm) followed by N_2 (from 445 to 477 mm). However, the minimum quantity was recorded in the N_4 treatment (from 400 to 435 mm). Variance analysis showed that there was no significant effect ($P \geq 0.05$) of nitrogen application on water consumption between treatments N_1 and N_2 during the three growing seasons. While, ANOVA analysis showed that there was significant effect ($P < 0.05$) if we compared N_1 to (N_3 and N_4) (and/or) N_2 to (N_3 and N_4) treatments. As a result, for the three experiments the cumulative water consumption in N_1 has recorded respectively an increase of (6.7, 8.9 and 6.6%) and (10.1, 15.5 and 9.8%) compared to N_3 and N_4. Similarly, the cumulative WC in N_2 has registered respectively an increase of (6.7, 4.5 and 5.7%) and (10.1, 11.4 and 8.8%) compared to N_3 and N_4. All through the Durum wheat growing season (Figure 2) the cumulative water consumption increased linearly with the cumulative total dry matter.

As shown by the results (Figure 2 and Table 3), the conversion efficiency of water consumption into dry matter production during wheat growing season and at harvest (WUE and WUE_F) were decreased by low nitrogen rates only during the first and third experiments (2005-2006 and 2007-2008). However, during the second experiment (2006-2007) variance analysis showed that there was no significant effect ($P \geq 0.05$) of nitrogen application on (WUE and WUE_F) between the four treatments.

Table 3. Conversion efficiency of water consumption into total dry matter production (WUE) at harvest for the three wheat growing seasons and under the four nitrogen treatments

Treatments	Cropping season								
	2005-2006			2006-2007			2007-2008		
	TDM_F	WC_F	WUE_F	TDM_F	WC_F	WUE_F	TDM_F	WC_F	WUE_F
N1	1254.6 a	445 a	2.81 a	1487.0 a	485 a	3.06 a	1362.0 a	482 a	2.82 a
N2	1222.6 a	445 a	2.74 a	1454.1 a	463 ab	3.14 a	1331.1 a	477 a	2.79 a
N3	1100.3 b	415 b	2.65 a	1300.1 b	442 b	2.94 a	1203.1 b	450 bc	2.67 a
N4	1038.9 c	400 b	2.59 b	1264.1 c	410 b	3.08 a	1058.7 c	435 c	2.43 b
LSD	**49.7**	**18.0**	**0.21**	**34.9**	**25**	**0.29**	**62.8**	**21**	**0.21**

Note. TDM_F: Total dry matter at wheat harvest (g m^{-2}); WC_F: cumulative water consumption at wheat harvest (mm); WUE_F: Conversion efficiency of water consumption into total dry matter production at wheat harvest (Kg m^{-3}); LSD: Least significant difference at 5%.

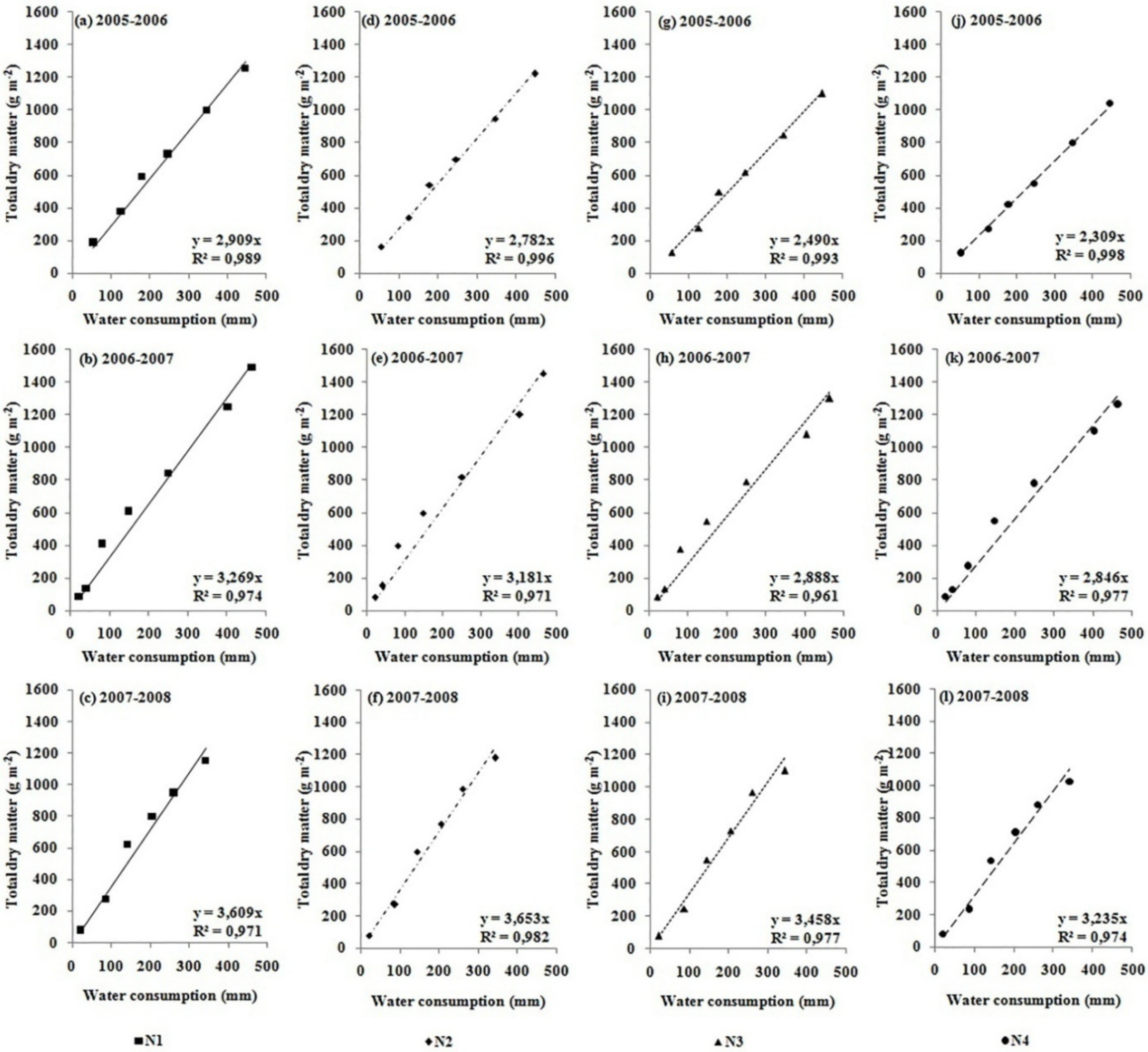

Figure 2. Relation between cumulative water consumption (mm) and cumulative total dry matter production (g m^{-2}) during the three growing seasons from 2005 to 2008 and under four nitrogen amount N_1 (a, b and c); N_2 (d, e and f); in N_3 (g, h and i) and in N_4 (j, k and l)

3.3 Relation between Photosynthetically Active Radiation Intercepted and Water Consumption

The relationship between photosynthetically active radiation intercepted and water consumption for the four treatments (N_1, N_2, N_3 and N_4) and during the three experiments (2006, 2007 and 2008) is given in Figure 3.

For the two treatments (N_1 and N_2) and during the three experiments (2006, 2007 and 2008), the cumulative PAR abs linearly increases with cumulative water consumption. The slope of these curves has varied from 0.45 to 0.47 10^{-3} m^3 MJ^{-1}. Nitrogen deficiency does not affect the founded linear correlation in treatment N_3 and N_4 (Figure 3). However, it was smaller than that in (N_1 and N_2). It was equal to 0.45 10^{-3} m^3 MJ^{-1} in N_3 and has ranged from 0.42 to 0.44 10^{-3} m^3 MJ^{-1} in N_4. From our results we observed that: (i) cumulative PAR abs accounted for a significant part of the variation in cumulative water consumption for wheat with different nitrogen supply, whereas (ii) the relation between the two concepts was basically unaffected by the treatments. A benefit of this relation is that the measurement of PARabs can be simply measured and modulated. In that case, it's possible to convert intercepted radiation into water needs by crops.

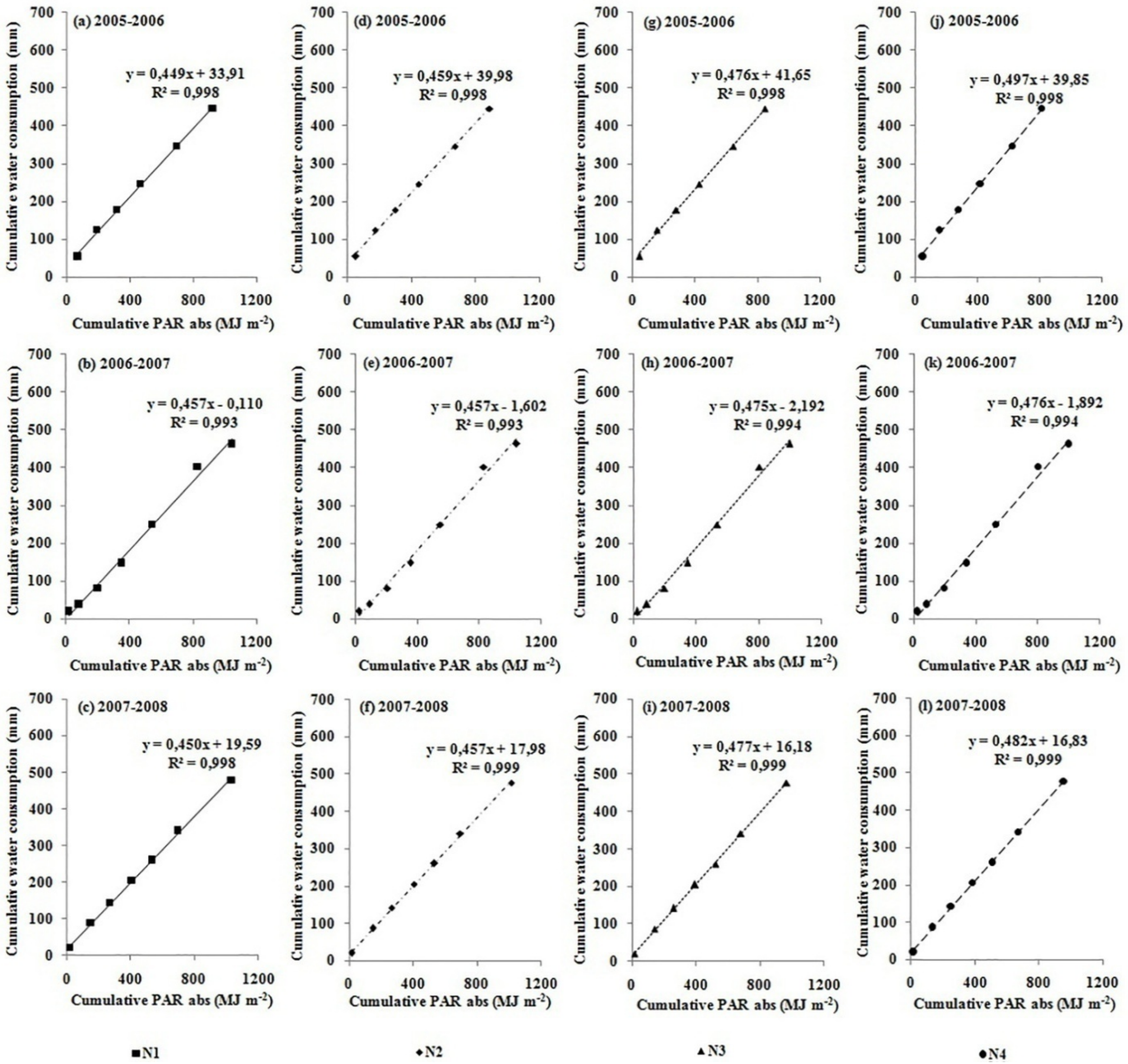

Figure 3. Relation between cumulative photosynthetically active radiation intercepted (MJ m^{-2}) and cumulative water consumption (mm) during the three growing seasons from 2005 to 2008 and under four nitrogen amount N_1 (a, b and c); N_2 (d, e and f); in N_3 (g, h and i) and in N_4 (j, k and l)

4. Discussion

The Total Dry Matter production (TDM); the Photosynthetically Active Radiation intercepted (PARabs); the conversion efficiency of photosynthetically active radiation intercepted into dry matter production (RUE and RUE_F); the water consumption (WC), the conversion efficiency of water consumption into dry matter (WUE and WUE_F) and the relation between photosynthetically active radiation intercepted and water consumption were investigated under different nitrogen rates (N_1, N_2, N_3 and N_4) during all cropping wheat season and at harvest (F).

As shown by the results (Figure 1 and Table 2), the conversion efficiency of photosynthetically active radiation intercepted into dry matter production during wheat growing season and at harvest (RUE and RUE_F) were decreased by low nitrogen rates (from N_1 to N_4). The highest amounts of (RUE and RUE_F) were obtained respectively during the three wheat growing seasons (2005-2006, 2006-2007 and 2007-2008) under the N_1 [(1.46 and 1.36); (1.50 and 1.43) and (1.79 and 1.32 g MJ^{-1})]. With reduced N, RUE and RUE_F decreased and the lowest values were observed respectively under N_4 [(1.31 and 1.27); (1.35 and 1.26) and (1.67 and 1.11 g MJ^{-1})]. To specify, the cumulative PARabs obtained respectively during the three experiments (2006, 2007 and 2008) under the N_1 treatment (920.2, 1041.5 and 1031.3 MJ m^{-2}) has decreased to (847.6, 997.4 and 966 MJ m^{-2}) and to (812.7, 999.4 and 954 MJ m^{-2}) respectively under N_3 and N_4. Consequently, for the three experiments the PARabs in N_1 has recorded respectively an increase of (7.9, 4.2 and 6.3%) and (11.7, 4.1 and 7.5%) compared to N_3 and N_4. Variance analysis showed that there was no significant effect ($P \geq 0.05$) of nitrogen application on RUE between treatments N_1 and N_2. However, ANOVA analysis showed that there was significant effect ($P < 0.05$) if compared (N1 or N2) to (N_3 and N_4) treatments. Similarly, N_1 enhanced the TDM compared to N_3 and N_4 rates, respectively from 11.7 to 12.6% and from 15 to 22.3%. Definitely, the RUE decrease in N_4 can be explained by the reduction in cumulative photosynthetically active radiation intercepted and total dry matter production. These results were in agreement with those of Shehzad et al. (2012). These authors studied the effect of four nitrogen rates (N_3 = 180 kg ha^{-1}, N_2 = 120 kg N ha^{-1}, N_1 = 60 kg ha^{-1} and N_0 = 0 kg ha^{-1}) on radiation use efficiency of wheat. They found that the RUE varied from 2.25 to 0.99 g MJ^{-1}. The highest value of RUE (2.25 g MJ^{-1}) was observed in N_3, followed by 1.90 g MJ^{-1} in N_2, 1.50 g MJ^{-1} in N_1 and the lowest RUE was achieved in N_0 and was equal to 0.99 g MJ^{-1}. Also, several researchers found that RUE is affected by the crop species, environmental conditions and crop nutritional status (Sinclair & Muchow, 1999; Muurinen & Peltonen-Sainio, 2006; Stöckle & Kemanian, 2009). The RUE decrease under low nitrogen rates has been published for different crops (Sinclair & Muchow, 1999; Massignam et al., 2009; Lemaire & Gastal, 2009). Similarly, Fletcher et al. (2013) and Dreccer et al. (2000) observed that nitrogen limitation affected wheat growth via reduction of the intercepted PAR. However, reduced RUE values can occur at extremely high nitrogen rates (Garcia et al., 1988; Olesen et al., 2000).

As shown by the results (Figure 2 and Table 3), the conversion efficiency of water consumption into dry matter production during wheat growing season and at harvest (WUE and WUE_F) have decreased by low nitrogen rates only during the first and third experiments (2005-2006 and 2007-2008). However, during the second experiment (2006-2007) variance analysis showed that there was no significant effect ($P \geq 0.05$) of nitrogen application on (WUE and WUE_F) between the four treatments. In fact, The highest amounts of (WUE and WUE_F) were registered respectively during the two wheat growing seasons (2005-2006, and 2007-2008) under the N_1 [(2.9 and 2.8) and (3.6 and 2.8 g MJ^{-1})]. With reduced nitrogen application, WUE and WUE_F decreased and the lowest values were observed respectively under N_4 [(2.6 and 2.6) and (3.4 and 2.4 g MJ^{-1})]. In detail, the cumulative water consumption obtained respectively during the three experiments (2006, 2007 and 2008) under the N_1 treatment (445, 485 and 482 mm) has decreased to (415, 442 and 450 mm) and to (400, 410 and 435 mm) respectively under N_3 and N_4. Thus, for the three experiments the cumulative water consumption in N_3 and N_4 has recorded respectively a decrease of (6.7; 8.9 and 6.6%) and (10.1; 15.5 and 9.8%) compared to N_1. Similarly, for total dry mater production, the TDM in N_3 and N_4 has recorded respectively a decrease of (12.3; 12.6 and 11.7%) and (17.2; 15 and 22.3%) next to N_1. Definitely, this WUE and WUE_F decrease in N_3 and N_4 during the first (2005-2006) and third experiment (2007-2008) can be explained by the high decline in total dry matter production followed by the small reduction in cumulative water consumption. Nevertheless, in the second experiment (2006-2007), the reduction in water consumption was more important. Our results are in agreement with several studies having shown that the N supply enhances crop productivity by improving WUE (Lajtha and Whitford, 1989; Shangguan et al., 2000; Ejaz & Ahmad, 2010). Likewise Qi et al. (2009) confirmed that Nitrogen fertilization can increase crop leaf area and dry matter accumulation. As well, Frederick and Camberato (1995) and Zhang et al. (1999) found increase WUE by promoting crop transpiration and reducing soil evaporation. Also, Eck (1988) found that winter wheat WUE increased with increments of N through 140 kg ha^{-1} on non-stressed treatments but it decreased on stressed treatments.

As shown by the results (Figure 3), during the three experiments (2006, 2007 and 2008) and for the four nitrogen treatments (N_1, N_2, N_3 and N_4), the cumulative PAR abs linearly increases with cumulative water consumption. Our results are in agreement with this of Teixeira et al. (2014). These authors illustrated strong linear relationship between the use efficiencies- of radiation interception and of transpired water, and they affirmed that the slope of this relationship is analogous to the inverse of crop conductance. Caviglia and Sadras (2001) and Teixeira et al. (2014) proclaimed that the small sensitivity of crop conductance to N treatments indicates that changes to transpired water use efficiencies in response to N supply were mostly driven by non-stomatal limitations. Similarly, Auzmendi et al. (2011), found under full irrigation and during the pre-harvest period a significant linear relationship between daily canopy transpiration (T_d) and daily canopy intercepted photosynthetically active radiation (IPARd) for apple tree. Similar relationships between water consumption and absorbed PAR accumulated were found for sole potato (Rezig et al., 2007, 2010; Sahli et al., 2003) and intercropping system sulla potatoes (Rezig et al., 2007, 2010). These relationships reflect the interdependence between resources use by crops. Also, Close associations between RUE and WUE were reported for sunflower and spring wheat (Sadras et al., 1991; Caviglia & Sadras, 2001). The relationships indicate the closely links between the use of radiation and water. A profit of this significant linear relation is that the measurement of PARabs can be simply measured and modulated. Subsequent to, it's possible to convert intercepted radiation into water needs by wheat.

5. Conclusion

This research indicates that nitrogen fertilization affect the total dry matter production (TDM), photosynthetically active radiation intercepted (PARabs), radiation use efficiency (RUE), water consumption (WC), Water use efficiency (WUE) of Durum Wheat (*Triticum durum* Desf). Results showed that, the cumulative PAR abs increase with increasing nitrogen levels. In fact, N_1 treatment recorded the highest cumulative PAR abs and the lowest obtained under without nitrogen treatment (D4). Also, RUE, TDM and WUE have increased with increasing nitrogen rates. The highest RUE, TDM and WUE observed under the N_1 treatment and the lowest under N_4 for three growing seasons (2005-2006, 2006-2007 and 2007-2008). The relationship between cumulative PAR abs and cumulative water consumption was linearly regression with a high correlation coefficient (R^2) which indicates that when cumulative PAR abs increases water consumption increases. For the profit of this significant linear relation, we conclude that it's possible to convert intercepted radiation into water needs by wheat.

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