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# Deficit Irrigation of Durum Wheat (*Triticum durum Desf*): Effects on Total Dry Matter Production, Light Interception and Radiation Use Efficiency Under Different Nitrogen Rates

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**Abstract**

On-farm trial was conducted from 2005 to 2008 to test the hypothesis that reduction of total dry matter (TDM) in crops can occur after a decreased radiation use efficiency (RUE) due to shortage of nitrogen and irrigation, we applied three irrigations treatments (D1, D2 and D3) and four nitrogen rates (N1, N2, N3 and N4). Photosynthetic active radiation absorbed or cumulative light interception (PARabs) and RUE of Durum wheat were measured. Results showed that D1N1 treatment recorded the highest LAI, PARabs, TDM and RUE. The maximum LAI was obtained 140 DAS (days after sowing) under treatment D1N2 (6.42) and the lowest LAI at the same phase belonged to treatment D2N4 (3.86). At the harvest, the maximum of TDM was 1487 g $m^{-2}$ recorded under treatment D1N1. The minimum value obtained was 930 g $m^{-2}$ under treatment D3N4. Also, PARabs was improved under D1N1 and D1N2 treatments. With reduced N application rates and irrigation doses, PARabs was decreased and the lowest values were observed under D3N4 condition. The RUE, varied from 1.55 g $MJ^{-1}$ (D1N1) to 1.24 g $MJ^{-1}$ (D3N4), was affected and decreased under deficit irrigation and low nitrogen conditions. In conclusion, the results of this study seem to show that D1N1 and D1N2 treatments can be beneficial for Durum wheat under field conditions in semi arid zone of Tunisia, for the purpose of improving RUE and maximizing grain yield.

**Keywords:** durum wheat, total dry matter, leaf area index, light interception, radiation use efficiency

## 1. Introduction

Durum wheat (*Durum Triticum Desf*) is one of the most important staple crops in the semi arid areas of North Africa. Agriculture in this region, especially in Tunisia is primarily based on rainfed cereals integrated with small ruminants production. Consequently, water deficiency and as well as low availability of nutrition (particularly nitrogen (N)) often limit wheat growth and its production potential (Oweis & Hachum, 2003). Reports have shown that wheat is sensitive to water and N at certain physiological growth stages. Nitrogen is the major mineral nutrient for plants and plays a central role in the production of all plant proteins (Sinclair & Weiss, 2010). In Tunisia, cereal yields are subject to significant fluctuations, given the inter-annual variability of rainfall (Sakiss et al., 1994). The scarcity and uneven distribution of precipitation in this area are a very serious problem especially in recent years, probably due to climate change. As N fertilizer responses are directly related to rainfall under dryland conditions (Campbell et al., 1993a; Pala et al., 1996), N use should be correspondingly greater and rational, when supplemental irrigation is applied. However, the response of wheat to irrigation water is dependent on the nitrogen applied (Aggarwal & Karla, 1994; Oweis et al., 1999). For this purpose, due to the growing water scarcity in Tunisia, as well as to the economic and environmental reasons, today's challenge lies in maximizing production using optimal and scheduled irrigation water doses that saves water (as deficit irrigation) and adequate supply of nitrogen fertilizer essential for the expansion and photosynthetic functioning of plant canopies (Grindlay, 1997). In fact, N deficiency reduces vegetative and reproductive growth with a final impact on the yield (Tewolde & Fernandez, 1997). Higher rates of N may shift the balance between vegetative and reproductive growth toward excessive vegetative development, thus delaying crop maturity and reducing final yield (Howard et al., 2001; Hamzei, 2011). Water deficit remarkably decreases the nitrogen translocation ratio derived from soil and adversely affects the contributions of nitrogen in various vegetative organs to grain nitrogen (Xu et al., 2006; Hamzei, 2011). Several water-saving methods have been developed (Belder et al., 2004; Bouman et al., 2006), among which, deficit irrigation is one of the best techniques that could improve irrigation water use. Variations in dry matter production in response to N availability could rise from differences in the amount of cumulative intercepted radiation by the canopy (IPARc, $MJ.m^{-2}$), the radiation use efficiency (RUE, g $MJ^{-1}$) and the partitioning between different organs. Determination of RUE is an important approach for understanding crop growth and yield production (Sinclair & Muchow, 1999; Katsura et al., 2007, 2008). Both photosynthetic rates and N content of leaves affect crop RUE. In this context, Muurinen and Peltonen-Sainio (2006), indicated that RUE of cereals varies seasonally and increases at increasing N application rates. When crop growth is not limited by other factors, the most appropriate measure for RUE is to fit a linear relationship between cumulative biomass accumulation and radiation interception (Sinclair & Muchow, 1999). When water stress occurs, the relationships among these parameters change and the crop's ability to capture light reduces (Williams & Boote, 1995). Under water stress conditions, the fraction of intercepted PAR and leaf area index were often used to evaluate the effects of drought stress on crops (Collino et al., 2001). Results recorded by Hamzei and Soltani (2012) showed that for rapeseed the higher RUE was recorded under moderate deficit irrigation (IR2, 4500 $m^3$ water $ha^{-1}$) and optimum N application (NN, 12 g $m^{-2}$). However, the integrated effect of deficit irrigation and nitrogen applications on the water consumption and yield of wheat requires more detailed studies. Also, no information is available on the interactive effects of nitrogen and irrigation regimes on biomass accumulation and radiation use efficiency for Durum wheat production in Tunisia. Therefore, the general objective of this paper was to investigate the appropriate irrigation regime and N rate to enhance Durum wheat biomass accumulation and RUE under the semi-arid conditions of Tunisia. This investigation will shed lights on the potential of reducing water and N-fertilizer consumption. Specific objectives of this study were (i) to determine how much increase in the Durum wheat biomass potential could be achieved by application of various N rates and irrigation regimes, (ii) to identify optimum amounts of nitrogen and water consumptions that contribute to the highest biological yield of (Durum wheat. cv. Karim), and (iii) to compare radiation use efficiency across nitrogen rates and irrigation regimes.

## 2. Materials and Methods

### *2.1 Experimental Site*

The experiment was carried out in field at the Private farm 'El Khir' located 30 km south of Tunis, Tunisia (36° 37' N, 10° 08' 25" E), during three successive growing seasons 2005/2006, 2006/2007 and 2007/2008. The climate is semi-arid. The annual rainfall average is about 400 mm. The soil had a clay texture with 180 mm $m^{-1}$ total available water and 1.8 g $l^{-1}$ water salinity. The soil bulk density varies from 1.25 to 1.55 from the surface to the depth. The Soil Organic Matter content (SOM %) are 1.22, 0.9, 0.75 and 0.75 respectively for 0-20 cm, 20-40 cm, 40-60 cm and 60-100 cm horizons. The pH of soil varies from 8.1 to 8.5.

### *2.2 Plant Material*

The plant material is composed of one variety of durum wheat "Triticum durum Desf" (Karim). Wheat was sawn at a rate of 180 Kg $ha^{-1}$ with a drill machine in 2005 on November 24$^{th}$, in 2006 on 31$^{th}$ November and in 2007 on the 17$^{th}$ of November.

### *2.3 Experimental Design*

The experiment covered two treatments ($T_1$: Nitrogen rates and $T_2$: water regimes). $T_1$ consisted of four nitrogen rates (N1=150 kg N/ha; N2= 100 kg N/ha; N3= 50 kg N/ha and N4= 0 kg N/ha). $T_2$ consisted of three water regimes and was monitored (D1 = Full irrigated with 100% ETM, D2 = 70% ETM and D3 = 40% ETM). The experimental design was Split Plot with 3 replications, allowing having 96 elementary plots. The main factor is irrigation regime and the secondary factor is nitrogen rates. Eight meters interval band was maintained between the water regimes treatments and two meters in the case of the nitrogen fertilization elementary plots. The application of all nitrogen rates tested were made 30 % at 6 leafs stage, 40% at tillering stage and 30% at stem elongation stage. Treatments descriptions of irrigation regimes are represented in Table 1.

Table 1. Treatment description

| Treatments | | Nitrogen rate (kg ha$^{-1}$) | Cropping season | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2005-2006 | | | | 2006-2007 | | | | 2007-2008 | | | |
| | | | Rain (mm) | Drai (mm) | Irri (mm) | ETC (mm) | Rain (mm) | Drai (mm) | Irri (mm) | ETC (mm) | Rain (mm) | Drai (mm) | Irri (mm) | ETC (mm) |
| | N1 | 150 | 280 | 55 | 220 | 445 | 347 | 21 | 190 | 516 | 348 | 11 | 150 | 487 |
| | N2 | 100 | 280 | 55 | 220 | 445 | 347 | 21 | 190 | 516 | 348 | 11 | 150 | 487 |
| | N3 | 50 | 280 | 55 | 220 | 445 | 347 | 21 | 190 | 516 | 348 | 11 | 150 | 487 |
| D1 | N4 | 0 | 280 | 55 | 220 | 445 | 347 | 21 | 190 | 516 | 348 | 11 | 150 | 487 |
| | N1 | 150 | 280 | 55 | 160 | 445 | 347 | 21 | 134 | 516 | 348 | 11 | 114 | 487 |
| | N2 | 100 | 280 | 55 | 160 | 445 | 347 | 21 | 134 | 516 | 348 | 11 | 114 | 487 |
| | N3 | 50 | 280 | 55 | 160 | 445 | 347 | 21 | 134 | 516 | 348 | 11 | 114 | 487 |
| D2 | N4 | 0 | 280 | 55 | 160 | 445 | 347 | 21 | 134 | 516 | 348 | 11 | 114 | 487 |
| | N1 | 150 | 280 | 55 | 105 | 445 | 347 | 21 | 76 | 516 | 348 | 11 | 78 | 487 |
| | N2 | 100 | 280 | 55 | 105 | 445 | 347 | 21 | 76 | 516 | 348 | 11 | 78 | 487 |
| | N3 | 50 | 280 | 55 | 105 | 445 | 347 | 21 | 76 | 516 | 348 | 11 | 78 | 487 |
| D3 | N4 | 0 | 280 | 55 | 105 | 445 | 347 | 21 | 76 | 516 | 348 | 11 | 78 | 487 |

P: Rainfall, Drai: Drainage, Irri: Irrigation, ETC: Crop Evapotranspiration.

### *2.4 Field Measurements*

#### 2.4.1 Climatic Data

Weather data were recorded daily by automatic agrometeorological station. Collected data were minimum and maximum temperatures (Tmin and Tmax), minimum and maximum air relative humidities (HRmin and HRmax), wind speed (V) and rainfall (P) during the three growing seasons (2005/2006; 2006/2007 and 2007/2008). Reference evapotranspiration (ET0) and solar radiation (Rs, MJ m$^{-2}$ d$^{-1}$) were estimated by the MABIA-ET0 software (Jabloun & Sahli, 2008) using the FAO-Penman-Monteith approach (Allen et al., 1998). The daily Rs were used to calculate the daily photosynthetically active radiation incident (PAR0 = RS/2) (Monteith & Unsworth, 1990).

#### 2.4.2 Leaf Area Index, Total Dry Matter Production and Radiation Use Efficiency

The observations were made on Leaf Area Index (LAI) and total dry matter (TDM g m$^{-2}$). In 2005-2006, sampling wheat was collected for growth analysis using one square meter after 45, 70, 99, 118, 138, 164, 204 days of sowing (DAS). In 2006-2007, the sampling was achieved at 45, 67, 92, 114, 134, 164, 198 DAS. In 2007-2008, plants were collected at 45, 83, 104, 124, 140, 160, 211 DAS. At each sampling date, LAI and dry matter weight were measured. 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.

### *2.5 Theoretical Formulations*

#### 2.5.1 Estimation of the Daily Radiation Interception

The fraction of intercepted radiation (Fi) was calculated from measurements of LAI using the exponential equation as suggested by Monteith and Elston (1983).

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

Where k is the extinction coefficient for total solar radiation. The k value of 0.45 was used for wheat as described by Jamieson et al. (1995).

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

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

Where PAR0 is photosynthetically active radiation incident, which is equal to half the solar radiation (Monteith & Unsworth, 1990).

#### 2.5.2 Estimation of the Radiation Use Efficiency

Radiation use efficiency (RUE) of wheat was calculated according the formula below:

$$\mathrm{RUE} = \frac{\mathrm{TDM}}{\mathrm{PARabs}} \quad (3)$$

### *2.6 Statistical Analysis*

Data collected for all measured parameters were subjected to tests of variance analysis, using Statistical Analysis System software (SAS, 1985). This variance analysis was completed by "multiple comparisons of means" with Newman Keuls test. LSD (Least Significant Difference) was used for comparing treatment group means at 0.05% (Little & Hill, 1978).

## 3. Results

### *3.1 Leaf Area Index*

Figure 1 shows the kinetics of Leaf area index LAI for the three wheat growing season at the various nitrogen rates (N1, N2, N3 and N4) and under the three irrigations rates (D1, D2 and D3).

As shown in Table 2, the differences between treatments (N1, N2, N3 and N4) under the three irrigation volumes (D1, D2 and D3) were significant ($P < 0.05$) at maximum growth.

In the 2005-2006 growing season, the highest LAI (4.91) was obtained 138 DAS from treatment D1N1 and the lowest LAI (3.86) at the same phase belonged to treatment D2N4. In the 2006-2007 growing season, the highest (5.78) and the lowest LAI (4.9) were obtained 134 DAS from treatment D1N1 and D2 N4 respectively. In the 2007-2008 growing season, the maximum (6.42) and minimum LAI (5.02) were achieved 140 DAS from D1N2 and D2N4 treatment respectively. The effect of irrigation on LAI was yearly depending. So in the first and the second experiment respectively at 138 and 134 DAS, ANOVAANOVA analysis shows that there is no significant effect ($P > 0.05$) of irrigation treatments on LAI. Nevertheless for the third experimentation 2007-2008, there was significant effect ($P < 0.05$) of irrigation treatment on LAI (Table 2). For the three experiments, ANOVA analysis shows that nitrogen application significantly ($P < 0.001$) increased the LAI. The maximum values of wheat Leaf area index (LAI max) were achieved for treatment (N1 and N2) and the lowest for treatment N4. The combined effect of irrigation regime and nitrogen application has a significant effect ($P < 0.01$) on LAI. So, for the three experiments (2006, 2007 and 2008), the maximum value of Leaf area index (LAI max) was recorded in treatment D1N1 for the first and the second experiment (4.91 and 5.78 respectively) and in D1N2 for the third experiment (6.42). The lowest LAI was respectively equivalent to (3.86; 4.9 and 5.02) in treatment D2N4.

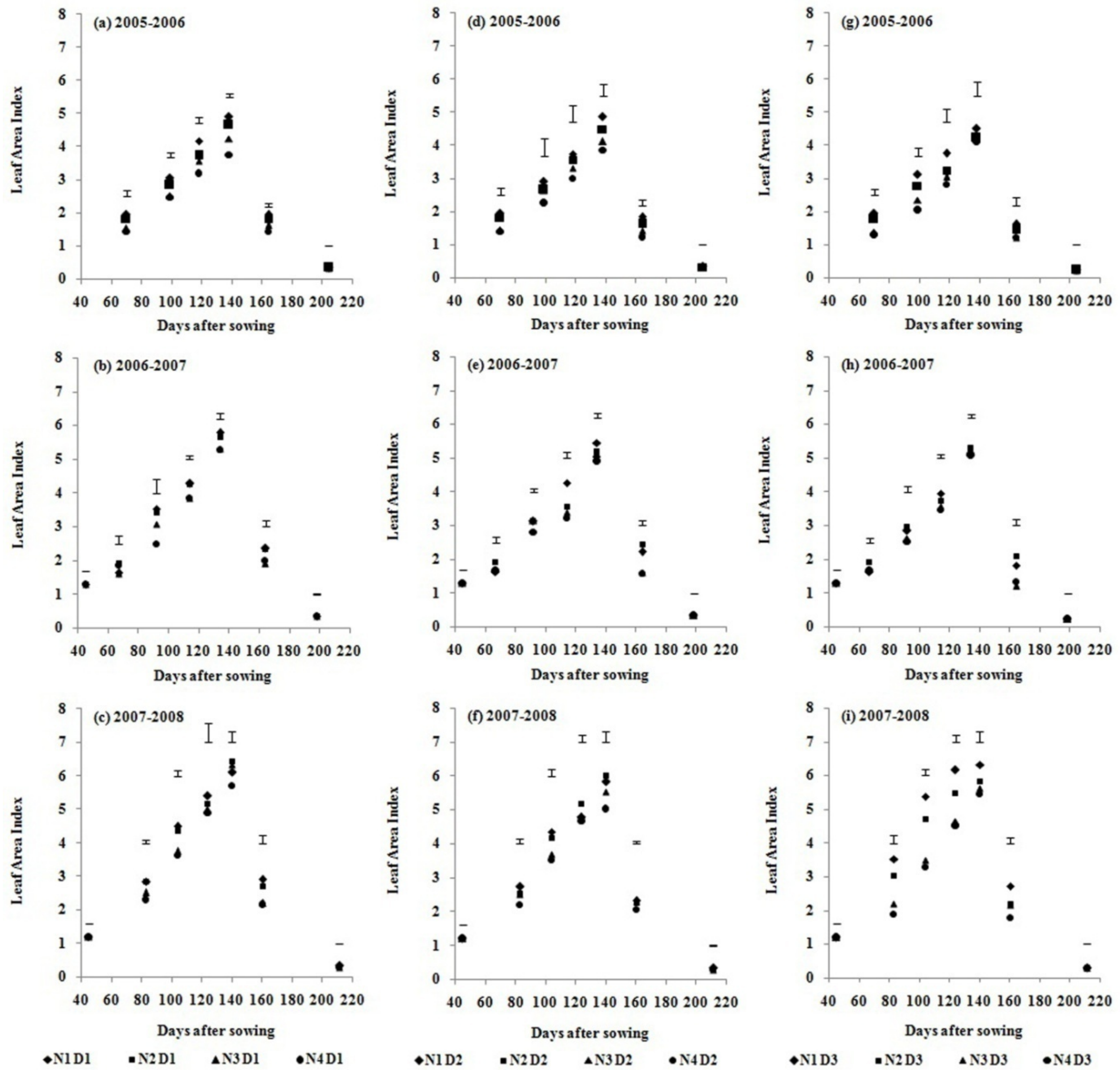


Figure 1. Leaf area index of wheat during the three experiments at the four nitrogen rates (N1, N2, N3 and N4) and under different water doses: D1 (a, b and c); D2 (d, e and f) and D3 (g, h and i). The vertical bars represent the least significant difference at 5% (LSD)

Table 2. Leaf area index of wheat at the four nitrogen rates (N1, N2, N3 and N4) and under three irrigation amounts (D1, D2 and D3) during the three campaigns (2006, 2007 and 2008)

| | 2005-2006 | | | | | | | 2006-2007 | | | | | | | 2007-2008 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DAS | 45 | 70 | 99 | 118 | 138 | 164 | 204 | 45 | 67 | 92 | 114 | 134 | 164 | 198 | 45 | 83 | 104 | 124 | 140 | 160 | 211 |
| D1N1 | 1.31 a | 1.94 a | 3.06 ab | 4.17 a | 4.91 a | 1.94 a | 0.3 a | 1.3 a | 1.62 c | 3.53 a | 4.27 a | 5.78 a | 2.37 ab | 0.3 a | 1.2 a | 2.85 c | 4.5 c | 5.4 b | 6.12 bc | 2.92 a | 0.3 a |
| D1N2 | 1.31 a | 1.82 ab | 2.83 cd | 3.73 b | 4.65 ab | 1.82 a | 0.3 a | 1.3 a | 1.91 a | 3.41 a | 4.26 a | 5.64 b | 2.33 ab | 0.3 a | 1.2 a | 2.85 a | 4.37 c | 5.16 bc | 6.42 a | 2.72 b | 0.3 a |
| D1N3 | 1.31 a | 1.68 bc | 2.52 efg | 3.57 bc | 4.23 c | 1.62 b | 0.3 a | 1.3 a | 1.62 c | 3.06 bc | 3.83 bc | 5.31 d | 1.9 e | 0.3 a | 1.2 a | 2.51 d | 3.75 e | 4.98 cd | 6.34 ab | 2.02 e | 0.3 a |
| D1N4 | 1.31 a | 1.6 c | 2.47 fg | 3.19 de | 3.74 e | 1.42 c | 0.3 a | 1.3 a | 1.85 ab | 2.47 f | 3.83 bc | 5.28 de | 1.99 de | 0.3 a | 1.2 a | 2.3 e | 3.62 ef | 4.9 cd | 5.7 ef | 2.16 cde | 0.3 a |
| D2N1 | 1.31 a | 1.95 a | 2.92 abc | 3.75 b | 4.86 a | 1.82 a | 0.3 a | 1.3 a | 1.64 c | 3.12 b | 4.26 a | 5.45 c | 2.22 bc | 0.3 a | 1.2 a | 2.73 c | 4.35 cd | 4.8 cde | 5.82 de | 2.32 c | 0.3 a |
| D2N2 | 1.31 a | 1.82 ab | 2.66 cdef | 3.57 bc | 4.5 b | 1.62 b | 0.3 a | 1.3 a | 1.91 a | 3.12 b | 3.54 d | 5.19 ef | 2.43 a | 0.3 a | 1.2 a | 2.53 d | 4.17 d | 6.16 a | 6.02 cd | 2.25 c | 0.25 b |
| D2N3 | 1.31 a | 1.68 bc | 2.64 def | 3.32 cd | 4.12 cd | 1.42 c | 0.3 a | 1.3 a | 1.72 bc | 3.13 b | 3.38 e | 5.11 fg | 1.61 f | 0.3 a | 1.2 a | 2.51 d | 3.69 e | 4.83 cde | 5.53 fg | 2.3 c | 0.25 b |
| D2N4 | 1.31 a | 1.6 c | 2.26 gh | 2.99 ef | 3.86 de | 1.23 d | 0.3 a | 1.3 a | 1.65 c | 2.79 de | 3.2 f | 4.9 h | 1.58 f | 0.3 a | 1.2 a | 2.18 e | 3.5 f | 4.65 de | 5.02 h | 2.06 de | 0.25 b |
| D3N1 | 1.31 a | 1.94 a | 3.12 a | 3.76 b | 4.52 b | 1.62 b | 0.2 b | 1.3 a | 1.64 c | 2.86 cd | 3.95 b | 5.1 fg | 1.82 e | 0.2 b | 1.2 a | 3.53 a | 5.37 a | 6.16 a | 6.32 ab | 2.72 b | 0.25 b |
| D3N2 | 1.31 a | 1.77 b | 2.78 cde | 3.25 de | 4.23 c | 1.45 c | 0.2 b | 1.3 a | 1.91 a | 2.97 bcd | 3.74 c | 5.29 de | 2.1 cd | 0.2 b | 1.2 a | 3.01 b | 4.69 a | 5.48 b | 5.83 de | 2.2 cd | 0.25 b |
| D3N3 | 1.31 a | 1.68 bc | 2.36 g | 3.05 def | 4.21 c | 1.22 d | 0.2 b | 1.3 a | 1.72 bc | 2.62 ef | 3.57 d | 5.22 de | 1.2 g | 0.2 b | 1.2 a | 2.18 e | 3.49 f | 4.64 de | 5.62 efg | 2.6 b | 0.25 b |
| D3N4 | 1.31 a | 1.6 c | 2.05 h | 2.81 f | 4.12 cd | 1.22 d | 0.2 b | 1.3 a | 1.65 c | 2.52 f | 3.46 de | 5.08 g | 1.33 g | 0.2 b | 1.2 a | 1.88 f | 3.27 g | 4.5 e | 5.43 g | 1.78 f | 0.25 b |
| LSD (5%) | 0 | 0.169 | 0.269 | 0.319 | 0.265 | 0.155 | 0.083 | 0 | 0.168 | 0.212 | 0.14 | 0.101 | 0.185 | 0.028 | 0 | 0.147 | 0.187 | 0.385 | 0.268 | 0.163 | 0.03 |
| D | 1 NS | 0.9275 NS | 0.1288 NS | 0.002** | 0.2701 NS | 0.0001*** | 0.0001*** | 0.0001*** | 0.9275 NS | 0.1288 NS | 0.0002*** | 0.2701 NS | 0.0001*** | 0.0001*** | 0.0001*** | 0.9275 NS | 0.1288 NS | 0.0002*** | 0.0001*** | 0.0001*** | 0.0001*** |
| N | 1 NS | 0.0001*** | 0.0001*** | 0.0001*** | 0.0001*** | 0.0001*** | 1 NS | 1 NS | 0.0001*** | 0.0001*** | 0.0001*** | 0.0001*** | 0.0001*** | 1 NS | 1 NS | 0.0001*** | 0.0001*** | 0.0001*** | 0.0001*** | 0.0001*** | 1 NS |
| D*N | 0.0014** | 0.9989 NS | 0.0942 NS | 0.8332 NS | 0.0068** | 0.4413 NS | 0.0001*** | 0.0014** | 0.9989 NS | 0.0942 NS | 0.8332 NS | 0.0068** | 0.4413 NS | 0.0001*** | 0.0014** | 0.9989 NS | 0.0942 NS | 0.8332 NS | 0.0068** | 0.4413 NS | 0.0001*** |

DAS: Days After Sowings, LSD: Least Significant Difference, * significant difference at 5%, ** significant difference at 0.01%, *** significant difference at 0.001%, NS no significant difference at 5%.

### *3.2 Total Dry Matter Production*

The Total dry matter accumulation of wheat (TDM) at the various nitrogen rates (N1, N2, N3 and N4) and under the three irrigations rates (D1, D2 and D3) was shown in Figure 2.

Total Dry Matter accumulation (TDM) presented a high variability according to the treatment and year (Figure 2 and Table 3). The maximum of TDM (1487 g $m^{-2}$) was recorded under treatment D1N1 in year 2. The minimum (930 g $m^{-2}$) was reached only in year 3 under treatment D3N4. The TDM was significantly ($P < 0.001$) affected by irrigation doses (D1, D2 and D3) in 2006, 2007 and 2008 growing seasons (Table 3). At harvesting, D1 increased the TDM in the treatment N1 compared to D2 and D3, respectively (from 2.9 to 5.8%) and (from 11.7 to 15.1%). Similarly, the treatment D1N2 has increased TDM compared to D2N2 and D3N2, respectively from 1.7 to 6.1% and from 6.1 to 15.9%. Likewise for the treatment D1N4 an increase in TDM was registered from 4.9 to 9.3% and from 6.9 to 13.2% next to in D2N4 and D3N4 respectively. ANOVA revealed that TDM was significantly ($P < 0.001$) influenced by nitrogen rates. Over all years and irrigation regimes, the wheat TDM was the greatest in the two treatments N1 and N2 and the least in the treatment N4 [Figure 2 and Table 3]. Treatments that not received nitrogen fertilizer produced the smallest TDM. Therefore, the application of nitrogen in N1 and N2 significantly ($P < 0.001$) increased TDM compared to N3 and N4. Indeed, in the irrigation regime D1, the treatment N1 improved the TDM compared to N3 and N4 rates, respectively from 11.7 to 12.6% and from 15 to 22.3%. Also, in the second regime D2, the treatment N1 has enhanced TDM compared to N3 and N4, respectively from 9.9 to 12.3% and from17.1 to 24.4%. Similarly, in the third regime D3, the TDM in N1 was higher than N3 and N4, respectively from 7.3 to 12% and from 12.8 to 22.7%. The combined effect of irrigation regime and nitrogen application had a significant effect ($P < 0.05$) on the TDM production only during the second and third experiments (Table 3). So, at harvest, the D1N1 has improved TDM compared to D4N4 about 23%, 26.2% and 31.7%, respectively for the three experiments 2006, 2007 and 2008.

Table 3. Total Dry Matter accumulation of wheat at the four nitrogen rates (N1, N2, N3 and N4) and under three irrigation doses (D1, D2 and D3) during the three campaigns (2006, 2007 and 2008)

| | 2005-2006 | | | | | | | 2006-2007 | | | | | | | 2007-2008 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DAS | 45 | 70 | 99 | 118 | 138 | 164 | 204 | 45 | 67 | 92 | 114 | 134 | 164 | 198 | 45 | 83 | 104 | 124 | 140 | 160 | 211 |
| D1N1 | 85 a | 190 a | 380 a | 590 a | 730 a | 1000 a | 1254.66 a | 85 a | 135.66 b | 410.66 a | 610 a | 840.33 a | 1249 a | 1487 a | 80 a | 275 a | 620 a | 800 a | 950 abc | 1150 ab | 1362.33 a |
| D1N2 | 85 a | 165 b | 340 bc | 540 b | 700 ab | 950 ab | 1222.66 ab | 85 a | 153.66 a | 400.66 a | 600.66 a | 820.33 ab | 1200.66 b | 1454.33 ab | 80 a | 270 a | 601 ab | 770 ab | 990 a | 1180 a | 1331 a |
| D1N3 | 85 a | 130 d | 280 ef | 500 c | 620 cd | 850 cd | 1100.33 de | 85 a | 135.33 b | 375.66 b | 550.33 b | 791 cd | 1080.66 de | 1300.33 d | 80 a | 250.66 ab | 550.33 cd | 730 bcd | 970 ab | 1100 bcd | 1203.33 bc |
| D1N4 | 85 a | 125 e | 270 f | 420 e | 550 f | 800 de | 1038.66 fg | 85 a | 127.66 c | 275 e | 550.33 b | 781 cde | 1100.33 cd | 1264.33 de | 80 a | 235.66 b | 531.66 de | 710 cd | 880.33 de | 1025.33 ef | 1058.66 e |
| D2N1 | 85 a | 190 a | 365 ab | 550 b | 710 ab | 950 ab | 1191.33 bc | 85 a | 135.66 b | 326 c | 600 a | 800.66 bc | 1130.66 c | 1401.33 c | 80 a | 265 a | 600 ab | 780 ab | 920 cd | 1140 ab | 1322 a |
| D2N2 | 85 a | 165 b | 320 dc | 510 c | 680 ab | 900 bc | 1148.33 cd | 85 a | 153.66 a | 325.66 c | 480.33 cd | 770.33 def | 1225.66 ab | 1430.66 bc | 80 a | 250 ab | 580.66 bc | 750 abc | 950 abc | 1120 bc | 1250 b |
| D2N3 | 85 a | 130 d | 290 def | 470 d | 610 de | 800 de | 1048.33 ef | 85 a | 135.33 b | 325.33 c | 460.66 d | 750.66 fg | 1040.66 ef | 1262 de | 80 a | 235.66 b | 530.33 de | 700 cd | 940 bc | 1080 cde | 1160.33 cd |
| D2N4 | 85 a | 125 e | 230 gh | 400 f | 575 de | 750 e | 987.66 ghi | 85 a | 127.66 c | 270.66 e | 430.33 e | 720.33 h | 1000.66 f | 1147.33 f | 80 a | 225 bc | 512 e | 680 de | 830.33 f | 975.33 fg | 1000.66 f |
| D3N1 | 85 a | 190 a | 380 a | 550 b | 670 bc | 900 bc | 1108.33 d | 85 a | 135.66 b | 275.66 e | 570.33 b | 760.66 ef | 1080.33 de | 1262.33 de | 80 a | 250 ab | 580 bc | 750 abc | 850 ef | 1050 de | 1203.33 bc |
| D3N2 | 85 a | 145 c | 305 de | 480 d | 615 d | 835 cd | 1027.66 fgh | 85 a | 153.66 a | 300.66 d | 550.66 b | 779.33 cde | 1100.66 cd | 1246.33 e | 80 a | 250.66 ab | 550.33 cd | 730 bcd | 880 de | 1080 cde | 1250 b |
| D3N3 | 85 a | 130 d | 260 fg | 410 ef | 570 def | 745 e | 975.66 hi | 85 a | 135.33 b | 265.33 e | 500 c | 750.33 fg | 920.66 g | 1170.33 f | 80 a | 225 bc | 512 e | 680 de | 820 fg | 975.33 fg | 1110.66 de |
| D3N4 | 85 a | 125 e | 210 h | 370 g | 560 ef | 740 e | 966.66 i | 85 a | 127.66 c | 255 e | 480.33 cd | 722.33 gh | 900.66 g | 1097.33 g | 80 a | 205 c | 460.66 f | 630 e | 800.33 g | 925 g | 930 g |
| LSD (5%) | 0 | 4.78 | 31.75 | 14.36 | 53.77 | 68 | 53 | 0 | 3.64 | 21.15 | 22.61 | 28.49 | 46.68 | 39.34 | 0 | 27.29 | 36.44 | 54.03 | 47.44 | 59.6 | 52.6 |
| D | 1 NS | 0.0011** | 0.0043** | 0.0001*** | 0.0068** | 0.0002*** | 0.0001*** | 1 NS | 1 NS | 0.0001*** | 0.0001*** | 0.0001*** | 0.0001*** | 0.0001*** | 1 NS | 0.0024** | 0.0002*** | 0.0035** | 0.0001*** | 0.0001*** | 0.0001*** |
| N | 1 NS | 0.0001*** | 0.0001*** | 0.0001*** | 0.0001*** | 0.0001*** | 0.0001*** | 1 NS | 0.0001*** | 0.0001*** | 0.0001*** | 0.0001*** | 0.0001*** | 0.0001*** | 1 NS | 0.0001*** | 0.0001*** | 0.0001*** | 0.0001*** | 0.0001*** | 0.0001*** |
| D*N | 1 NS | 0.0001*** | 0.0955 NS | 0.0003*** | 0.3988 NS | 0.9189 NS | 0.1327 NS | 1 NS | 1 NS | 0.0001*** | 0.0001*** | 0.1961 NS | 0.0032** | 0.0008*** | 1 NS | 0.9433 NS | 0.8378 NS | 0.961 NS | 0.3184 NS | 0.7291 NS | 0.023* |

DAS: Days After Sowings, LSD: Least Significant Difference, * significant difference at 5 %, ** significant difference at 0.01 %, *** significant difference at 0.001 %, NS no significant difference at 5 %.

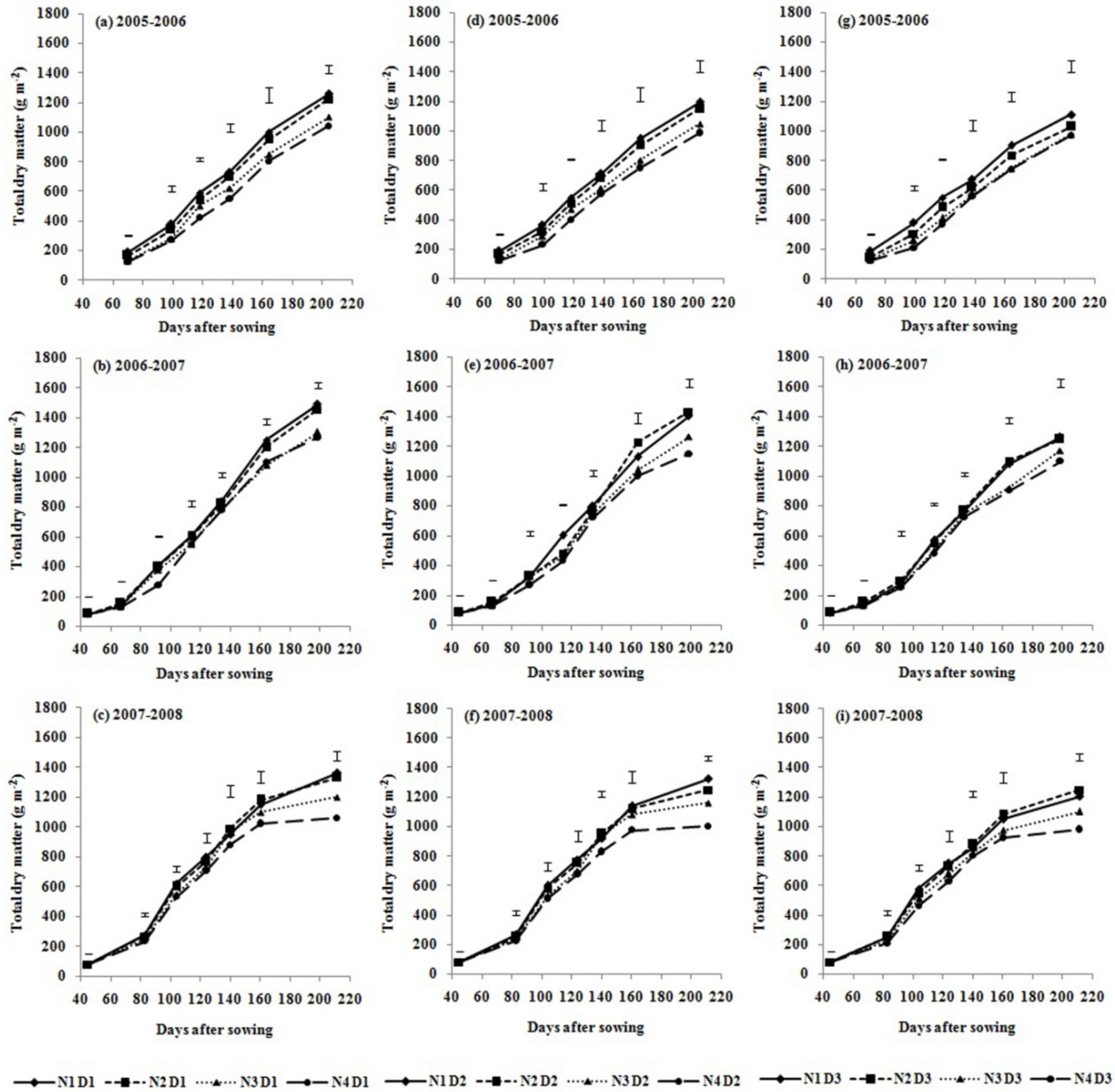


Figure 2. Total dry matter accumulation of wheat during the three experiments 2006; 2007 and 2008 at four nitrogen rates (N1, N2, N3 and N4) under irrigation doses D1 (a, b and c); D2 (d, e and f) and D3 (g, h and i). The vertical bars represent the least significant difference at 5% (LSD)

### *3.3 Radiation Interception*

The cumulative radiation interception of wheat (PARabs) at the various nitrogen rates (N1, N2, N3 and N4) and under the three tested irrigations rates (D1, D2 and D3) are shown in Figure 3.

Data analysis showed that at harvesting, the PARabs was significantly ($P < 0.01$) affected by irrigation regimes (D1, D2 and D3) in 2006, 2007 and 2008 growing seasons [Figure. 3 and Table 4]. The irrigation regime D1 has increased respectively (PARabs) in the treatment N1 about (13.6; 16.4 and 67.3 MJ $m^{-2}$) and (42.8; 93 and 99 MJ $m^{-2}$) relative to in D2 and D3. Similarly, the D1 enhanced PARabs in the treatment N2 compared to D2 and D3 respectively, (23.4; 8.1 and 63.6 MJ $m^{-2}$) and (55.4; 35.1 and 81.1 MJ $m^{-2}$). Likewise for the treatment N4, D1 increased respectively PARabs about (3.3; 4.2 and 4.3%) and (5.4; 7.2 and 9.1%) compared to D2 and D3.

For the three experiments, results revealed that the cumulative PARabs was significantly ($P < 0.001$) influenced by nitrogen rates. Therefore, the application of nitrogen in N1 and N2 rates increased the radiation interception compared to N3 and N4 rate. In fact, in the irrigation regime D1, the treatment N1 has increased respectively

PARabs (from 4.3 to 7.9% and from 4.1 to 11.7%) compared to the treatment N3 and N4. Also, in the second regime D2, the treatment N1 has enhanced PARabs (from 1.9 to 9 % and from 5.2 to 13.3 %) next to the treatment N3 and N4. Similarly, in the third regime D3, the treatment N1 has raised respectively PARabs (from 2.2 to 10.6% and from 2.2 to 12.3%) compared to N3 and N4.

Variance analysis showed that there was no significant effect ($P < 0.05$) of interaction between irrigation regime and nitrogen rates on the cumulative $PAR_{abs}$. However, this combined effect has a consequence on the cumulative PARabs during the three experiments. So, at harvesting, the cumulative $PAR_{abs}$ in treatment D1N1 was respectively equal to (920.2; 1041.5 and 1031.3 MJ $m^{-2}$) and it was respectively equivalent to (769.3; 927.7 and 867.7 MJ $m^{-2}$) for wheat in treatment D3N4.

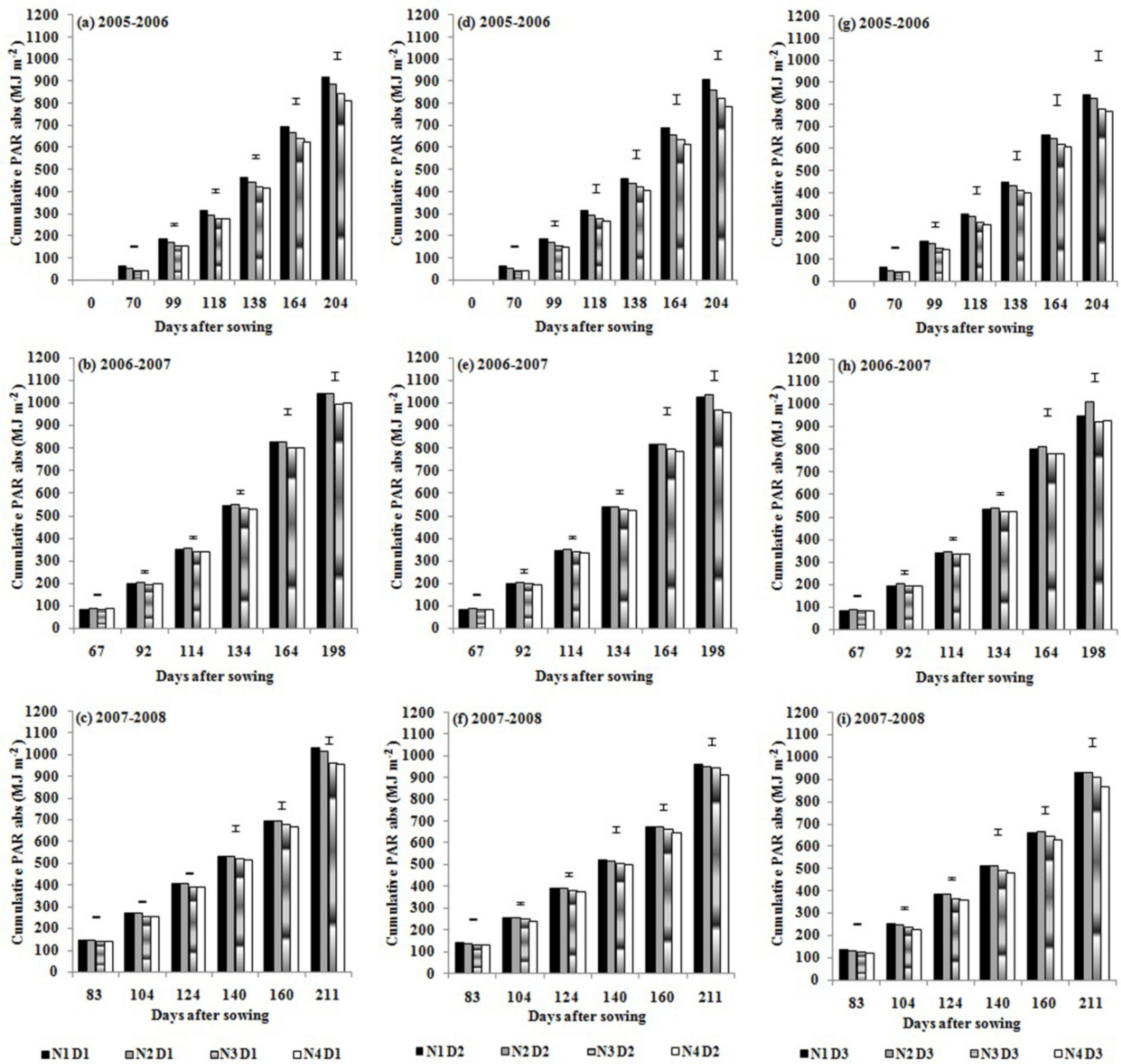


Figure 3. Time course of estimated cumulative light interception of wheat (PAR abs) in D1, D2 and D3 during the LAI measurement periods from 2006 to 2008. The vertical bars represent the least significant difference at 5% (LSD)

Table 4. Cumulative light interception of wheat (PAR abs) at various nitrogen rates (N1, N2, N3 and N4) and under three irrigation doses (D1, D2 and D3) during the three campaigns (2006, 2007 and 2008)

| | 2005-2006 | | | | | | 2006-2007 | | | | | | 2007-2008 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DAS | 70 | 99 | 118 | 138 | 164 | 204 | 67 | 92 | 114 | 134 | 164 | 198 | 83 | 104 | 124 | 140 | 160 | 211 |
| D1N1 | 64.9 a | 187.8 a | 316.8 a | 465.2 a | 695.1 a | 920.2 a | 83.1 b | 200.6 a | 350.7 ab | 544.7 ab | 825.0 a | 1041.5 a | 145.8 a | 267.6 a | 405.8 a | 533.6 a | 695.9 a | 1031.3 a |
| D1N2 | 50.6 b | 169.9 bc | 295.8 b | 442.2 abc | 668.0 abcd | 885.6 abc | 86.4 a | 205.8 a | 355.4 a | 549.0 a | 828.1 a | 1042.7 a | 145.8 a | 267.1 a | 404.6 a | 532.5 a | 694.4 a | 1013.9 a |
| D1N3 | 45.9 c | 157.9 cd | 281.1 c | 425.4 bcd | 643.6 bcdef | 847.6 cde | 83.0 b | 196.5 a | 342.4 abcd | 533.7 abc | 804.2 abcd | 997.4 cd | 140.8 ab | 257.6 ab | 393.1 ab | 520.7 ab | 679.0 ab | 966.0 b |
| D1N4 | 44.4 cd | 154.5 cd | 274.8 cd | 415.2 cd | 623.3 def | 812.7 ef | 85.8 a | 195.8 a | 338.2 bcd | 529.4 abc | 801.2 abcd | 999.4 cd | 137.3 abc | 252.1 abc | 386.9 ab | 513.7 abc | 669.8 ab | 954.0 bc |
| D2N1 | 64.9 a | 186.4 ab | 312.8 a | 459.9 ab | 687.7 ab | 906.6 ab | 83.3 b | 197.6 a | 345.9 abc | 539.1 abc | 815.6 ab | 1025.1 abc | 139.5 ab | 258.3 ab | 393.6 ab | 519.5 abc | 674.9 ab | 964.0 b |
| D2N2 | 50.6 b | 168.1 c | 292.1 b | 437.4 abc | 658.2 abcde | 862.2 cd | 86.4 a | 203.5 a | 347.0 abc | 537.8 abc | 815.5 abc | 1034.6 ab | 136.3 abc | 253.2 abc | 388.9 ab | 515.5 abc | 671.1 ab | 950.3 bc |
| D2N3 | 45.2 cd | 158.2 cd | 280.5 c | 423.3 cd | 635.9 cdef | 825.3 def | 84.2 ab | 199.4 a | 342.9 abcd | 531.7 abc | 795.1 abcd | 971.8 de | 136.1 abc | 250.4 bc | 383.7 abc | 509.2 abc | 663.5 abc | 946.0 bc |
| D2N4 | 43.7 de | 150.3 d | 267.5 d | 407.4 cd | 612.0 ef | 786.4 fg | 83.5 b | 194.7 a | 334.7 cd | 521.8 c | 782.7 bcd | 957.4 ef | 130.4 bc | 241.2 cd | 373.2 bc | 497.5 bcd | 647.5 bc | 913.5 c |
| D3N1 | 64.9 a | 188.3 a | 315.7 a | 461.8 a | 682.7 abc | 877.4 bc | 83.3 b | 195.1 a | 340.6 bcd | 531.7 abc | 799.2 abcd | 948.5 efg | 135.8 abc | 252.4 abc | 385.9 abc | 510.3 abc | 662.3 abc | 932.3 bc |
| D3N2 | 49.9 b | 168.1 c | 290.8 b | 433.8 abcd | 648.2 abcdef | 830.2 de | 86.4 a | 202.1 a | 347.0 abc | 537.9 abc | 811.5 abcd | 1007.6 bc | 132.6 abc | 248.5 bc | 383.7 abc | 509.5 abc | 662.7 abc | 932.8 bc |
| D3N3 | 44.1 d | 152.4 cd | 270.8 d | 412.7 cd | 621.3 def | 784.7 fg | 84.2 ab | 194.4 a | 336.0 cd | 526.0 bc | 781.1 cd | 921.8 g | 127.9 bc | 237.3 cd | 368.3 bc | 493.0 cd | 645.1 bc | 912.4 c |
| D3N4 | 42.3 e | 144.4 d | 258.2 e | 398.3 d | 605.9 f | 769.3 g | 83.5 b | 191.7 a | 331.9 d | 521.0 c | 777.9 d | 927.7 fg | 122.0 c | 227.3 d | 356.8 c | 480.9 d | 628.4 c | 867.7 d |
| LSD (5%) | 1.64 | 17.64 | 8.11 | 36.22 | 51.11 | 41.6 | 2.28 | 14.58 | 13.99 | 19.66 | 34.44 | 32.05 | 15.39 | 16.01 | 29.11 | 26.57 | 38.61 | 43.59 |
| D | 0.0472* | 0.6069 NS | 0.0027** | 0.5488 NS | 0.4076 NS | 0.0007*** | 0.9143 NS | 0.5186 NS | 0.1152 NS | 0.1245 NS | 0.0417* | 0.0001*** | 0.0057 NS | 0.0005*** | 0.0174* | 0.0042** | 0.0081** | 0.0001*** |
| N | 0.0001*** | 0.0001*** | 0.0001*** | 0.0004*** | 0.0007*** | 0.0001*** | 0.0016** | 0.1336 NS | 0.0106* | 0.0199* | 0.009** | 0.0001*** | 0.0811 NS | 0.0031** | 0.0615 NS | 0.0272* | 0.0679 NS | 0.0001*** |
| D*N | 0.6934 NS | 0.9743 NS | 0.1414 NS | 0.9984 NS | 1 NS | 0.9855 NS | 0.4674 NS | 0.9977 NS | 0.9808 NS | 0.9911 NS | 0.996 NS | 0.1353 NS | 0.9939 NS | 0.9591 NS | 0.9967 NS | 0.9959 NS | 0.9994 NS | 0.361 NS |

DAS: Days After Sowings, LSD: Least Significant Difference, * significant difference at 5 %, ** significant difference at 0.01 %, *** significant difference at 0.001 %, NS no significant difference at 5 %.

### *3.4 Radiation Use Efficiency*

The radiation use efficiency of wheat (RUE) in the three irrigation level (D1, D2 and D3) and during the three experiments (2005; 2006 and 2007) is given in Figure 4. RUE presents a high variability according to the treatments and years (Figure 4 and Table 5). The maximum of RUE (1.59 g $MJ^{-1}$) was recorded under treatment D2N1 in year 3. The lowest RUE value (1.24 g $MJ^{-1}$) was recorded in year 2 under treatment D3N4. Data analysis showed that RUE was significantly ($P < 0.001$) affected by irrigation regimes (D1, D2 and D3) in 2006, 2007 and 2008 (Table 5).

In the end of maturity stage, the irrigation regime D1 has improved respectively RUE in the treatment N1 (from 3.4 to 6%) and (from 6.8 to 8.7%) relative to in D2 and D3. Similarly, the D1 enhanced respectively RUE in the treatment N2 (from 1.4 to 3.4%) and (from 8.3 to 9.6%) relative to in D2 and D3. Likewise for the treatment N4, D1 increased respectively RUE (from 1.5 to 6.7%) and (from 2.3 to 8.1%) relative to D2 and D3.

The RUE was the greatest in both N1 and N2 treatments and the least in the treatment N4 overall years and irrigation regimes (D1, D2 and D3) [Figure. 4 and Table 5]. ANOVA revealed that RUE was significantly ($P < 0.001$) influenced by N rates. Therefore, the two treatments N1 and N2 increased significantly RUE compared to N3 and N4. In fact, in the irrigation regime D1, the treatment N1 has improved respectively RUE from 2.6 to 8.7% and from 10 to 10.3% compared to N3 and N4. Also, in the second irrigation regime D2, the treatment N1 has enhanced RUE compared to N3 and N4, respectively from 5.7 to 6.4% and from 8.5 to 13.2%. Similarly, in the third irrigation regime D3, the treatment N1 has improved respectively RUE from 5.3 to 6.6% and from 5.9 to 9.5% compared to N3 and N4.

Variance analysis showed that there was no significant effect ($P < 0.05$) of interaction between irrigation regime and nitrogen rates on RUE. For the three experiments (2006, 2007 and 2008), the RUE in treatment D1N1 was respectively equal to 1.46; 1.5 and 1.55 g $MJ^{-1}$ and it was respectively equivalent to 1.28; 1.24 and 1.38 g $MJ^{-1}$ in treatment D3N4.

Table 5. Radiation use efficiency of wheat (RUE) at the four nitrogen rates (N1, N2, N3 and N4) and under the three irrigation doses (D1, D2 and D3) during the three growing season (2006, 2007 and 2008)

| | 2005-2006 | | 2006-2007 | | 2007-2008 | |
|---|---|---|---|---|---|---|
| | RUE | $R^2$ | RUE | $R^2$ | RUE | $R^2$ |
| D1N1 | 1.46 a | 0.96 | 1.5 a | 0.98 | 1.55 abc | 0.91 |
| D1N2 | 1.46 a | 0.97 | 1.45 b | 0.98 | 1.56 abc | 0.91 |
| D1N3 | 1.36 bc | 0.97 | 1.37 cd | 0.98 | 1.51 abc | 0.9 |
| D1N4 | 1.31 cd | 0.98 | 1.35 de | 0.98 | 1.39 d | 0.86 |
| D2N1 | 1.41 ab | 0.96 | 1.41 bc | 0.99 | 1.59 a | 0.93 |
| D2N2 | 1.41 ab | 0.96 | 1.43 b | 0.99 | 1.57 ab | 0.91 |
| D2N3 | 1.32 cd | 0.97 | 1.32 ef | 0.99 | 1.50 c | 0.90 |
| D2N4 | 1.29 d | 0.98 | 1.26 g | 0.99 | 1.38 d | 0.86 |
| D3N1 | 1.36 bc | 0.95 | 1.37 cd | 0.99 | 1.51 bc | 0.91 |
| D3N2 | 1.32 cd | 0.96 | 1.33 de | 0.98 | 1.54 abc | 0.93 |
| D3N3 | 1.28 d | 0.97 | 1.28 fg | 0.98 | 1.43 d | 0.90 |
| D3N4 | 1.28 d | 0.98 | 1.24 g | 0.98 | 1.38 d | 0.89 |
| LSD (5%) | 0.067 | | 0.045 | | 0.066 | |
| D | 0.0004*** | | 0.0001*** | | 0.0053** | |
| N | 0.0001*** | | 0.0001*** | | 0.0001*** | |
| D*N | 0.5574 NS | | 0.1191 NS | | 0.2728 NS | |

DAS: Days After Sowings, LSD: Least Significant Difference, * significant difference at 5 %, ** significant difference at 0.01 %, *** significant difference at 0.001 %, NS no significant difference at 5 %.

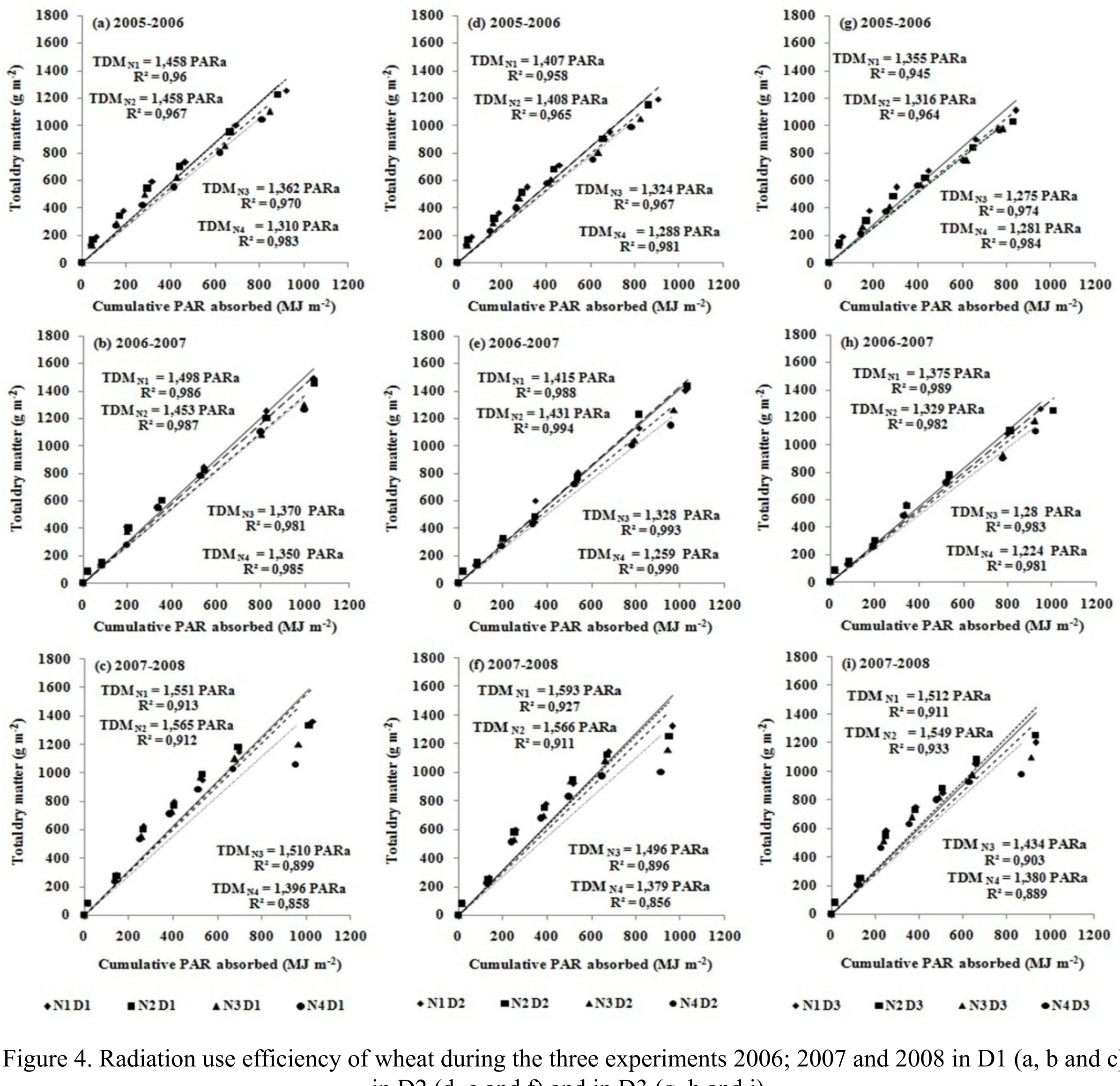


Figure 4. Radiation use efficiency of wheat during the three experiments 2006; 2007 and 2008 in D1 (a, b and c); in D2 (d, e and f) and in D3 (g, h and i)

### *3.5 Discussion*

The combinated effects of the three irrigation amount (D1, D2 and D3) and the four nitrogen rates (N1, N2, N3 and N4) on the leaf area index (LAI), total dry matter production (TDM), radiation interception (PARabs) and radiation use efficiency (RUE) were investigated. As shown by the results (Table 2), LAI was decreased by deficit irrigation and low nitrogen rates (Figure 1). These results were in agreement with those of Khaliq et al. (1999). The latter authors observed that an increase in nitrogen content of soil affects all growth stages of wheat. Salvagiotti and Miralles (2008) found that an increase in nitrogen concentration at anthesis can result in an increase of LAI by as much as 62% and IPAR by up to 20%. As well, numerous researchers affirmed that under nitrogen shortage the leaf area expansion decreases and senescence increases (Vos & Biemond, 1992; Massignam et al., 2011). Likewise, these results are consistent with those of Collinson et al. (1999). These authors reported that the water deficit reduces the solar radiation interception due to rolling up the leaves and they observed that the number and size of leaves may be reduced or the total leaf area may decrease, if the water deficit is prolonged. In fact, the optimum nitrogen (N2), high doses (N1) and irrigation amount (D1) had greater contributions to leaf expansion as a consequence of higher growth rate of leaf area. Furthermore, we observed that irrigation amount and nitrogen application rates affect the TDM accumulation. This effect could be due to water availability in (D2 and D3) and to the low nitrogen accessibility for plant under (N3 and N4) treatments, which in result in the aboveground growth restriction. Definitely, the highest amount of TDM was obtained under the D1N1 condition (Table 3). With reduced nitrogen (N3 and N4) and irrigation application rates (D2 and D3), TDM decreased and the lowest values was observed under D3N4 condition. These findings are in line with those of Gan et al. (2008), Ali et al. (2009), Hamzei (2011) and Hamzei et al. (2012). They observed that increasing nitrogen levels increase the biological yield of the crop. Ezzat-Ahmadi (2002) showed that the level of 160 kg of nitrogen produced the highest yield. MacDonald (2002) examined different nitrogen levels on the yield of different wheat cultivars and he observed that dry matter at anthesis significantly increased at increased nitrogen. Tewolde and Fernandez (1997) confirmed that the nitrogen deficiency reduces vegetative and reproductive growth with a final impact on the yield due to leaf senescence. Nevertheless, Nielsen et al. (2002) reported that the wheat grain yield, photosynthesis, and total dry matter accumulation decreased with over-fertilization of nitrogen. Therefore, determination of the appropriate amount of nitrogen for dry land wheat is important, so that the growers can optimize yields and improve their grain quality without over fertilizing with N that might increase N leaching potential (Halvorson et al., 2004). As analyses indicated, irrigation regimes and nitrogen rates had significant effects on cumulative radiation interception (Table 4). In fact, the highest amount of cumulative PARabs was obtained under the D1NI condition. With reduced N application rates and irrigation doses, PARabs also decreased and the lowest values were observed under D3N4 condition. According to Caviglia and Sadras (2001), the LAI were reduced in crops grown under nitrogen deficiency. Also, Dreccer et al. (2000) observed that low nitrogen conditions affected wheat growth via reduction of the intercepted PAR. The reduction should be on the leaf area dynamics to limit IPAR in arid environments (O'Connell et al., 2004; Miranzadeh et al., 2011). As shown by data (Table 5), RUE was affected and decreased under deficit irrigation and low nitrogen conditions (figure 4). The RUE varied from 1.55 g $MJ^{-1}$ (D1N1) to 1.24 g $MJ^{-1}$ (D3N4). These findings are in line with those Gregory et al. (1992); Yunusa et al (1993); Latiri-Souki et al. (1998). They found that for wheat in semi-arid conditions and at different irrigation and nitrogen levels, the conversion efficiency of the incident PAR varies between 0.9 g $MJ^{-1}$ for treatments without irrigation and without nitrogen and 1.5 g $MJ^{-1}$ for treatments with irrigation and nitrogen. However, the conversion efficiency calculated for PAR intercepted, the values are higher and vary between 1.4 g $MJ^{-1}$ and 2.9 g $MJ^{-1}$ between treatments. Furthermore, these results were in agreement with those of Caviglia and Sadras (2001) and Muurinen and Peltonen-Sainio (2006). They affirmed that the RUE of wheat was reduced when nitrogen was limited. Similarly, Fletcher et al. (2013) observed that under nitrogen deficit the RUE with 200 kg N $ha^{-1}$ was 1.66 g $MJ^{-1}$ PAR, which fell by 22% to 1.30 g $MJ^{-1}$ PAR when no N-fertilizer was applied. Wilson and Jamieson (1985) observed in arid environments, that water stress tends to reduce RUE progressively by preventing utilization of photosynthates for growth as lower IPAR occurs from reduced LAI. Likewise, the reductions in RUE due to water deficits have been reported by Hughes and Keatinge (1983) in grain legumes. In this study, TDM accumulation was positively related to interception of PAR (Figure. 4), which is a finding in line with the results reported by other researchers (Li et al., 2009; Miranzadeh et al., 2011, Rezig et al., 2013a, 2013b). Miralles and Slafer (1997) indicated that post-anthesis RUE appeared to be closely and positively associated with the number of grains set per unit biomass at anthesis in winter wheat. Whitfield and Smith (1989), Chen et al. (2003), and Li et al. (2008) showed that crop yield was positively related to RUE in winter wheat. Equally, different crops have been found to be closely correlated with cumulative radiation intercepted by their foliage e.g. Sulla (Rezig et al., 2013b), green been (Rezig et al., 2010, 2013a) and potato (Rezig et al., 2010, 2013a, 2013b).

## 4. Conclusion

LAI, TDM, PARabs and RUE were affected by different irrigation regimes and nitrogen rates. Nitrogen application (N1 = 150 kg N/ha and N2 = 100 kg N/ha) and full irrigation could accelerate leaf area development and help to intercept more radiation for dry matter production. In fact, water deficit in D3 and nitrogen deficiency (N3 = 50 kg N/ha and N4 = 0 kg N/ha) treatments caused a high reduction of TDM followed by a greater LAI sensitivity. Higher RUE (1.56 g $MJ^{-1}$) was recorded under full irrigation (D1) combined with optimum N application (N2 = 100 kg N/ha) and the lowest values (1.24 g $MJ^{-1}$) was observed under deficit irrigation and nitrogen deficiency (D3N4). So, D1N1 and D1N2 treatments can be recommended for durum wheat .cv. Karim under field conditions in semi arid zone of Tunisia in order to improve RUE and maximize the yield. Further studies on the influence of nitrogen × irrigation interactions on RUE are needed to enhance water use efficiency and yield potential of durum wheat .cv. Karim under different conditions.

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