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Impact of Deficit Irrigation (DI) and Root-Zone Drying Irrigation Technique (PRD) under Different Nitrogen Rates on Radiation Use Efficiency for Potato (*SolanumTuberosum L.*) in Semi-arid Conditions (II)

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***Abstract*—*The study was carried out at the Technical Center of Potato and Artichoke CTPTA located in the lower valley of Medjerda river of Tunisia during the season of 2017. The purpose was to estimate the impact of deficit irrigation (DI) and the root-zone drying irrigation technique (PRD) under different nitrogen rates on photo synthetically active radiation absorbed and radiation use efficiency for Potato (SolanumTuberosum L. VS. Spunta). Three water treatments (T_1= 100% ETC, T_2 = DI = 75% ETC and T_3 = PRD_{50}) and three nitrogen rates (F_1 = N_{150}: 150 kg N ha^{-1}, F_2 = N_{75}: 75kg N ha^{-1}, F_3 = N_0: 0kg N ha^{-1}) were applied since the tuber initiation (55 days after planting) to maturity (100 days after planting).The deficit irrigation T_2 has no effect on PARabs. Besides, the PRD_{50} has led to a reduction in PARabs. This decrease compare to T_1 was equal to (8.9; 9.9 and 7.9%) respectively for the three treatments (F_1; F_2 and F_3). The nitrogen deficit affects negatively the PARabs. An improvement of 13.2%, 11.2% and 12.2% of the F_1 compared to the F_3, respectively for the three water treatments (T_1, T_2 and T_3). The T_2 has no effect on RUE $_{TDM}$. Conversely, the PRD_{50} has led to a reduction in RUE $_{TDM}$. This decline referee against T_1 was equal to (12.7; 17.4 and 21.5%) respectively for the three treatments (F_1; F_2 and F_3). For RUE_{GY} statistical analysis showed significant ($P < 0.05$) difference between the three irrigation treatments (T_0, T_1 and T_2) for the three nitrogen treatments (F_1; F_2 and F_3). The T_2 and the PRD_{50} has led to a reduction in RUE $_{GY}$. This decrease judge against T_1 respectively for the two treatments (F_2 and F_3) was equal to (14.9 and 21.5%) and (19.6 and 31.2%).*

Keywords*—*Deficit Irrigation, Root-Zone Drying Irrigation, Leaf Area Index, Photosynthetically Active Radiation Absorbed, Radiation Use Efficiency.

I. INTRODUCTION

Increasing crops productivity and saving irrigation water are two interrelated issues raising a lot of concern these days in Tunisia. Deficit irrigation is an optimization strategy in which irrigation is applied during the drought-sensitive growth stages of a crop. Outside these times, irrigation is limited or even unnecessary if rainfall provides a minimum water supply. Restriction of water is limited to drought tolerant phenology. In other terms, deficit irrigation aims to stabilize yields and achieve maximum water gain rather than maximum yields (Zhang and Oweis, 1999). Deficit irrigation practices differ from traditional water supply follow. The manager needs to know the level of permissible sweating deficit without significant yield reduction of the crop. The main objective of deficit irrigation is to increase the water use efficiency of a crop with no impact on yield. According to English et al., (1990), Partial Root-zone Drying (PRD) is a modified form of deficit irrigation (DI), which consists of watering only a part of the soil of the root zone in each irrigation event, leaving the other part to dry to certain soil moisture content before re-wetting by moving the irrigation to the dry side. Therefore, PRD is a new irrigation strategy in which half of the roots are placed in soil drying and the other half grow in irrigated soil (Ahmadi et al., 2010a). Wetting and drying on both sides of the roots depend on the crop, stage of growth, evaporation, crop requirements, soil texture and soil moisture balance (Saeed et al., 2008). The PRD irrigation has been the subject of many researchers (Samadi & Sepaskhah, 1984; Bahrun et al., 2002; Kang & Zhang, 2004; Gencoglan et al., 2006; Shahnazari et al., 2007; Shayannejad, 2009; Wang et al., 2013).Potato (Solanumtuberosum L.) is a water demanding crop, requiring from 450 to 800 L to produce 1 kg of tuber dry matter (Wright & Stark, 1990). Several studies have been done to analyze the dry matter growth of a crop based on the intercepted radiation. Monteith (1972) is the first to discover the role of crop in the solar radiation absorption and in the transformation of intercepted energy into biomass. The efficiency of this transformation is known as the radiation use efficiency, which is defined as the ratio of the biomass produced to the amount of energy received (Bonhomme, 2000). Indeed, in the absence of any source of stress (water, nutrition or sanitation), several authors have reported the existence of a strong linear relationship between the development of a given crop and the radiation intercepted for several plant species (Scott et al. al., 1973). The water deficit significantly affects radiation use efficiency as well as total dry matter production and photosynthetically active radiation absorbed. Deficit irrigation causes leaf curl and reduced leaf number and size which cause reduction in total leaf area. It also reduces photosynthesis by inducing leaf senescence, which in turn leads to a decrease in the light use efficiency. Nitrogen and water limitation affected biomass yield, the efficiencies of radiation, water and nitrogen use in maize crops (Teixeira et al., 2014). Fletcher et al. (2013) affirmed that over nitrogen deficit the RUE, decreased by 22% 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 PAR occurs from reduced LAI. Likewise, the reductions in RUE due to water deficits have been reported by Hughes and Keatinge (1983) in grain legumes. Beneath water deficit, the photosynthetically active radiation absorbed and leaf area index were frequently used to estimate the effects of drought stress on crops (Collino et al., 2001). Hamzei and Soltani (2012) confirmed that the higher RUE was marked under moderate deficit irrigation and optimum nitrogen rate. Nevertheless, the combined effect of deficit irrigation and nitrogen application on the radiation use efficiency of potato need more detailed studies. Also, no information is available on the interactive effects of nitrogen and irrigation regimes on biomass accumulation and radiation interception for potato in Tunisia. Therefore, the objective was to investigate the suitable irrigation regime and N rate to improve potato biomass accumulation and RUE under the semi-arid conditions of Tunisia. This investigation will discard the potential of reducing water and Nitrogen fertilizer utilization.

II. MATERIALS AND METHODS

Experimental Site

The experiment was carried out at the Technical Centre of Potato situated in the low valley of Medjerda river at Saida, Tunisia (10°EST, 37°N, Alt. 28 m), during the season 2017.

The climate is semi arid. The average annual rainfall is about 450 mm, concentrated from December to April with irregular distribution.

The soil had a clay-loam texture with 180 mm m-1 total available water and 2 g l^{-1} water salinity. The bulk density varies from 1.34 to 1.60 from the surface to the depth (Rezig et al., 2013a).

Plant Material and Experimental Design

Plant material consisted of one potato variety (Solanumtuberosum cv. Spunta). The potato planting was conducted on 02 March 2017 with a mechanical planter machine. The Planting density was 41667 plants ha^{-1}.

The experiment covered two treatments (T: water regimes and F: nitrogen rates). T consisted of three water regimes (T_1 = 100% ET_C, T_2= 75% ET_C and T_3= PRD_{50}).

F consisted of three nitrogen rates (F_1 = 150 kg N ha^{-1}, F_2 = 75 kg N ha^{-1} and F_3 = 0 kg N ha^{-1}).

At the beginning of the potato cycle (during the first stages) irrigation and fertilization were started without any difference between the treatments (with the exception of the F_3 which did not receive nitrogen from the beginning), from which the crop was given 100% of the water needs and nitrogen requirements in a homogeneous way over the entire plot.

The experimental protocol was started 26 April 2017 (**55** DAP) at the stage of the initiation of tuberisation to potato harvesting and they were irrigated by drip irrigation. The experimental design was Split Plot with 3 replications. The main factor is irrigation regime and the secondary factor is nitrogen rates.

Field measurements

Climatic Data

Weather data were recorded daily by automatic agrometeorological station. Collected data were minimum and maximum temperatures (T_{min} and T_{max}), minimum and maximum air relative humidities (HR_{min} and HR_{max}), wind speed (V) and rainfall (P). Reference evapotranspiration (ET0) and solar radiation (Rs, MJ m^{-2} d^{-1}) were estimated by the Cropwat 8.0 software 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).

Leaf Area Index, Total Dry Matter Production

The observations were made on Leaf Area Index (LAI) and total dry matter (TDM g m^{-2}). The sampling was collected for growth analysis at 40, 56, 69, 85 and 96 days after planting Potato (DAPP). Each sample was placed separately in a plastic bag with an identification tag. After separation of the various parts, the quantity of fresh material was determined immediately. As for the amount of dry matter, it was measured after drying at 80 °C to a constant mass. The weightings were carried out using a precision scale (Model PB3001, Mettler Brand, Switzerland). Leaf area was measured using planimeter type CID Inc-Cl-202.

Theoretical Formulations

Estimation of the Daily Photosynthetically Active Radiation Intercepted

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

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

Where k is the extinction coefficient for total solar radiation. The k value of 0.60 was used for potato as described by Rezig et al., (2013a).

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

$$\mathbf{PARabs = PAR_0 * Fi \quad (2)}$$

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

Estimation of the radiation use efficiency

RUE of total dry matter (RUE_{TDM}) and RUE of potato yields (RUE_{GY}) were calculated using the following equation:

$$\mathbf{RUE_{TDM}\ (kg\ m^{-3}) = TDM / PARabs \quad (3)}$$

$$\mathbf{RUE_{GY}\ (kg\ m^{-3}) = GY / PARabs \quad (4)}$$

Where, RUE is the radiation use efficiency (g MJ^{-1}), TDM is the total dry matter production (g m^{-2}), GY is the potato yields (kg) and PARabs is the total Photosynthetically Active Radiation Intercepted over the whole potato growing season (mm).

2.6. Statistical Analysis

The results were subjected to variance analysis of one factor by General Linear Model (GLM). This analysis was performed using SPSS 20.0 software. The set was completed by multiple comparisons of means with Student Newman Keuls test (S-N-K).

III. RESULTS

Effect of Deficit Irrigation (DI) and Partial Root-Zone Drying Irrigation (PRD) and on Leaf Area Index.

The impact of irrigation treatment (T_1 = 100% ETC, T_2 = 75% ETC and T_3= PRD_{50}) in the leaf area index (LAI) of potato was given in figure 1. In order to make out the effect of water regime on the evolution of leaf area index. The LAI was followed for the three treatments T_1, T_2 and T_3. The results illustrated that during the primary 65th DAP, the LAI curves of all treatments track the same pace.

Indeed, the differences between irrigation treatments are observed after applied the water stress. It is noted that the LAI increases gradually to reach its maximum at the 77th DAP, and from this date, the value of the LAI decreases until the end of the cycle.

For the three nitrogen treatments F_1, F_2 and F_3, the maximum values of the LAI are recorded respectively in the T_1 (3.8; 3.5 and 3.1) followed by the T_2 treatment (3.3; 2.9 and 2.7) and finally the treatment T_3 (2.9; 2.5 and 2.3).

From these results, we observed that the deficit irrigation T_2 (ETC = 75 %) and the Partial Root-Zone Drying Irrigation (PRD_{50}) has led to a reduction in LAI_{max}.

This decline compare to T_1 for the three treatments (F_1, F_2 and F_3) was equal respectively to (13.1; 17.2 and 12.9%) and (23.7; 28.6 and 25.8%). To observe the deficit nitrogen effect of on the evolution of LAI. The evolution of LAI was followed according to days after planting for the three treatments F_1, F_2 and F_3.

The results obtained showed that the increase of the nitrogen dose led to an improvement of the LAI_{max}. The greatest values of the LAI are recorded in the F_1 (3.8; 3.3 and 2.9) followed by the F_2 treatment (3.5; 2.9 and 2.5) and finally the treatment F_3 (3.1; 2.7 and 2.3) for the three irrigation treatments T_1, T_2 and T_3 respectively. The results show that the nitrogen deficit affects negatively the LAI_{max}. An enhancement of 18.4%, 18.2% and 20.7% of the F_1 treatment compared to the F_3 treatment, respectively for the three water treatments (T_1, T_2 and T_3).

Table.1: the leaf area index (LAI) of potato under the three irrigation treatments and the three nitrogen rates.

DAP	**42**	**55**	**62**	**70**	**77**	**84**	**92**
T_1 F_1	1.3a	2.0a	2.6a	3.1a	3.8 a	2.9 a	1.8a
T_2 F_1	1.2a	1.9a	2.4a	2.9b	3.3 b	2.7 b	1.4a
T_3 F_1	1.1a	1.7a	2.2a	2.7b	2.9 c	2.4 c	1.3a
LSD	0.5	0.7	0.8	0.2	0.41	0.2	0.6
T_1 F_2	1.1a	1.9a	2.3a	2.9a	3.5 a	2.7 a	1.6a
T_2 F_2	0.9a	1.8a	2.1a	2.6a	2.9 b	2.4 b	1.4a
T_3 F_2	0.8a	1.7a	2.1a	2.4a	2.5 c	2.2 c	1.3a
LSD	0.47	0.8	0.9	0.9	0.40	0.3	0.5
T_1 F_3	0.9a	1.6a	2.1a	2.5a	3.1 a	2.3 a	1.3a

DAP	**42**	**55**	**62**	**70**	**77**	**84**	**92**
T_2 F_3	0.8a	1.5a	2.7a	2.4a	2.7 a	2.3 a	1.3a
T_3 F_3	0.7a	1.4a	1.9a	2.3a	2.3 a	2.1 a	1.2a
LSD	0.5	0.7	0.9	0.8	0.9	0.5	0.5
T_1 F_1	1.3a	2.0a	2.6a	3.1a	3.8 a	2.9 a	1.8a
T_1 F_2	1.1a	1.9a	2.3a	2.9a	3.5 a	2.7 a	1.6a
T_1 F_3	0.9a	1.6a	2.1a	2.5a	3.1 a	2.3 b	1.3a
LSD	0.7	0.9	0.9	1.1	0.7	0.4	0.8
T_2 F_1	1.2a	1.9a	2.4a	2.9a	3.3 a	2.7 a	1.4a
T_2 F_2	0.9b	1.8a	2.2b	2.6a	3.0 b	2.4 b	1.4a
T_2 F_3	0.8b	1.5b	2.1b	2.4b	2.7 b	2.3 b	1.3a
LSD	0.3	0.3	0.3	0.35	0.30	0.3	0.6
T_3 F_1	1.1a	1.7a	2.2a	2.7a	2.9 a	2.4 a	1.3a
T_3 F_2	0.8b	1.7a	2.1a	2.4a	2.5 b	2.2 ab	1.3a
T_3 F_3	0.7b	1.4b	1.9a	2.3b	2.3 b	2.1 b	1.2a
LSD	0.3	0.3	0.7	0.35	0.40	0.2	0.6

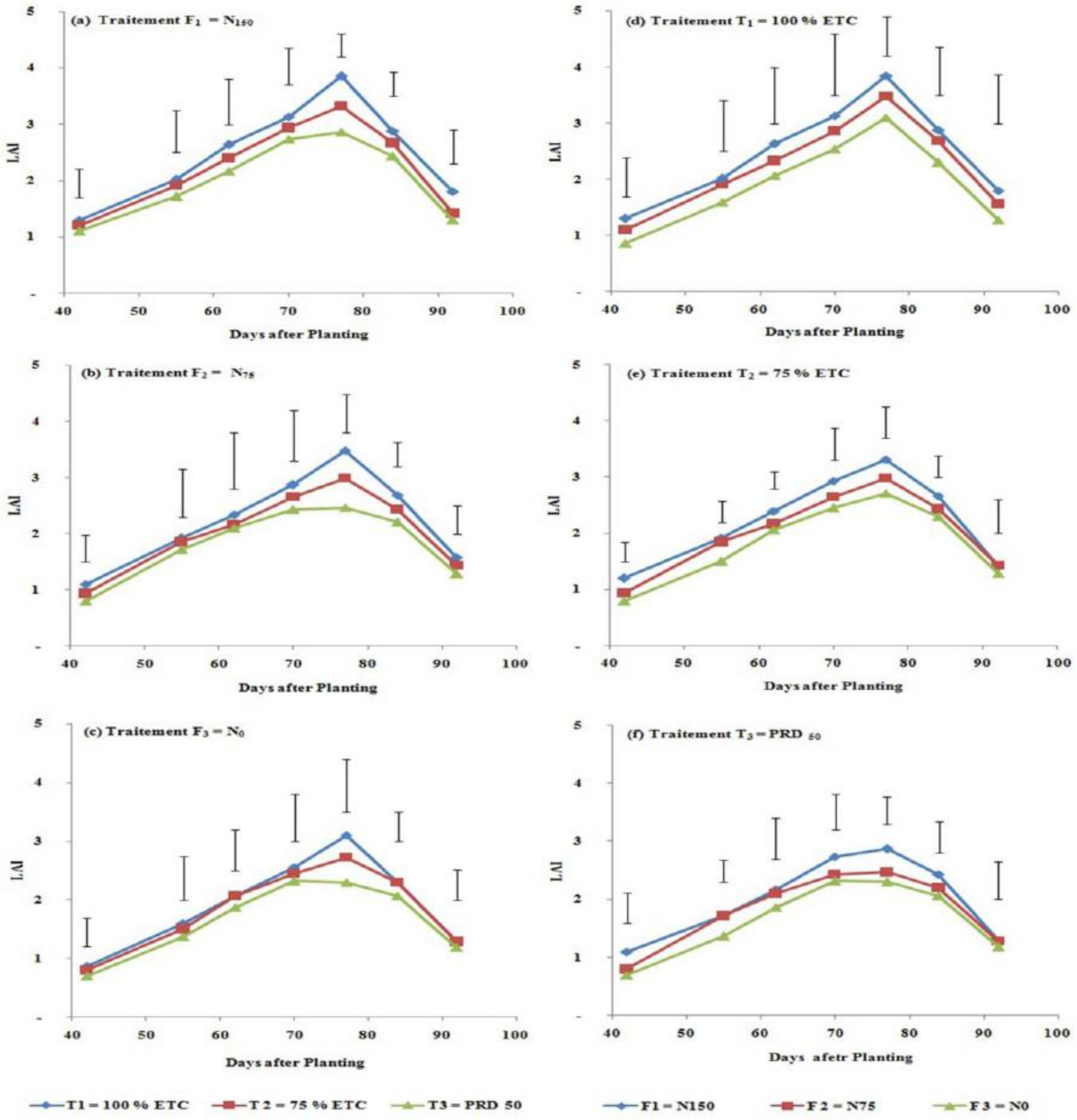

Fig.1: The Leaf Area Index (LAI) of potato under the three irrigation treatments (T_1, T_2 and T_3) and the three nitrogen rates (F_1, F_2 and F_3).

Effect of PRD and DI on Photosynthetically Active Radiation Absorbed.

The effect of three irrigation treatments (T_1 = 100% ET_C, T_2= 75% ET_C and T_3= PRD_{50}) and the three nitrogen rates (F_1 = 150 kg N ha^{-1}, F_2 = 75 kg N ha^{-1}and F_3 = 0 kg N ha^{-1}) in the photosynthetically active radiation absorbed (PARabs) of potato was given in figure 2. ANOVAs analysis (Table 2) confirmed that the cumulative PARabswere significantly ($P < 0.05$) affected by the irrigation treatment (T_1; T_2 and T_3). For the three treatments F_1, F_2 and F_3, the highest PARabswas recorded respectively under T_1 (516.5; 490.1 and 448.4 MJm^{-2}) and T_2 (494.9; 467.6 and 439.7 MJm^{-2}). The smallest was observed under T_3 (470.3; 441.8 and 412.9 MJm^{-2}). From these outcome, we observed that the deficit irrigation T_2 (ETC = 75 %) has no effect on PARabs. Moreover, the Partial Root-Zone Drying Irrigation (PRD_{50}) has led to a reduction in PARabs. This decrease compare to T_1 was equal to (8.9; 9.9 and 7.9%) respectively for the three treatments (F_1; F_2 and F_3). In order to examined the effect of deficit nitrogen on the cumulative PARabs. It's was measured for the three treatments F_1, F_2 and F_3.The results obtained showed that the increase of the nitrogen dose led to an improvement of the PARabs. The greatest values of the PARabs are recorded in the F_1 (516.5; 494.9 and 470.3 MJ m^{-2}) followed by the F_2 treatment (490.1; 467.6 and 441.8 MJ m^{-2}) and finally the treatment F_3 (448.4; 439.7 and 412.9) for the three irrigation treatments T_1, T_2 and T_3 respectively. The results show that the nitrogen deficit affects negatively the PARabs. An improvement of 13.2%, 11.2% and 12.2% of the F_1 treatment compared to the F_3 treatment, respectively for the three water treatments (T_1, T_2 and T_3).

Effect of PRD and DI on Radiation Use Efficiency.

The relation between the cumulative photosynthetically active radiation absorbed (PARabs) and the total dry matter production (TDM) over all potato growing season and under the nine treatments is given in Figure 3. From these outcomes, we observed for different treatments that the TDM increased linearly with the cumulative PAR absorbed. The slope of this regression is the conversion efficiency of radiation interception into total dry matter production (RUE). We distinguished that, for the treatment F_1, the highest amount of RUE was recorded in the T_2 treatment 1.53 g MJ^{-1} and after that in T_1 1.47 g MJ^{-1}. However, the smallest amount was recorded in the T_3 treatment 1.24 g MJ^{-1}. In detail, the RUE in T_2 has demonstrated respectively an increase of 3.9% and 18.9 % compared to T_1 and T_3. Nevertheless, for the two treatments F_2 and F_3, the highest RUE was recorded in the T_1 treatment (1.35 and 1.28 g MJ^{-1}) and after that in T_2 (1.31 and 1.17 g MJ^{-1}). The least was recorded in the T_3 treatment (1.30 and 1.10 g MJ^{-1}). In denote, for the two nitrogen rate (F_2 and F_3) the RUE in T_2 and T_3 has demonstrated respectively a decline of (3.7 and 8.6%) and (3.7 and 14.1 %) compared to T_1. The radiation use efficiency of total dry matter production at harvest (RUE_{TDM}) and the radiation use efficiency of yield (WUE_{GY}) of the nine treatments were exposed in Table 3.

Table.2:the photosynthetically active radiation absorbed (PARabs) of potato under the three irrigation treatments (T_1, T_2 and T_3) and the three nitrogen rates (F_1, F_2 and F_3).

DAP	**62**	**70**	**77**	**84**	**92**
T_1 F_1	208.2a	288.0a	368.7a	443.5a	516.5 a
T_2 F_1	200.0a	277.6a	355.3a	427.2a	494.9 a
T_3 F_1	187.9a	262.7a	337.1a	405.6a	470.3 b
LSD	25.8	30.1	32.7	43.6	24.6
T_1 F_2	193.7a	270.1a	348.2a	420.7a	490.1 a
T_2 F_2	183.9a	257.9a	332.6a	401.7b	467.6 ab
T_3 F_2	172.7a	244.5a	314.7a	379.5c	441.8 b
LSD	36.6	39.8	59.5	19.5	23.2
T_1 F_3	170.4a	242.6a	316.8a	385.2a	448.4 a
T_2 F_3	165.6a	237.5a	309.5a	376.5a	439.7 a
T_3 F_3	153.3a	222.3a	290.3a	353.3b	412.9 b
LSD	26.6	32.3	54.8	23.2	26.8
T_1 F_1	208.2a	288.0a	368.7a	443.5a	516.5 a
T_1 F_2	193.7a	270.1a	348.1a	420.7a	490.1 ab
T_1 F_3	170.4a	242.6a	316.8a	385.2a	448.4 b
LSD	45.2	101.9	52.9	33.1	67.2

T_2 F_1	200.0a	277.6a	355.3a	427.2a	494.9 a
T_2 F_2	183.9b	257.9b	332.6b	401.7b	467.6 b
T_2 F_3	165.6c	237.5c	309.5c	376.5c	439.7 c
LSD	20.6	20.5	23.1	25.7	27.3
T_3 F_1	187.9a	262.7a	337.1a	405.6a	470.3 a
T_3 F_2	172.7b	244.5b	314.7b	379.5b	441.8 b
T_3 F_3	153.3c	222.3c	290.3c	353.3c	412.9 c
LSD	17.5	23.8	22.9	25.9	28.4

Table.3: Radiation use efficiency (g MJ^{-1}) of total dry matter at harvest (RUE_{TDM}) and radiation use efficiency (g MJ^{-1}) of yield (RUE_{GY}) under the three irrigation treatments and the three nitrogen rates.

DAP	**TDM**	**Yield**	**PAR abs**	**RUE TDM**	**RUE YD**
T_1 F_1	1539.3 a	20.3 a	516.5 a	2.98 a	3.94 a
T_2 F_1	1511.2 a	20.7 a	494.9 a	3.05 a	4.18 a
T_3 F_1	1223.5 b	13.0 b	470.3 b	2.60 b	2.77 b
LSD	88.0	3.6	24.6	0.36	0.76
T_1 F_2	1493.7 a	20.7 a	490.1 a	3.05 a	4.23 a
T_2 F_2	1382.4 b	16.8 b	467.6 ab	2.96 a	3.60 b
T_3 F_2	1111.4 c	14.6 c	441.8 b	2.52 b	3.31 b
LSD	110.6	2.2	47.2	0.38	0.85
T_1 F_3	1463.4 a	22.4 a	448.4 a	3.26 a	5.00 a
T_2 F_3	1311.1 b	17.7 b	439.7 a	2.98 a	4.02 b
T_3 F_3	1055.2 c	14.2 c	412.9 a	2.56 b	3.44 b
LSD	132.8	2.7	83.8	0.41	0.80
T_1 F_1	1539.3 a	20.3 b	516.5 a	2.98 a	3.94 b
T_1 F_2	1493.7 ab	20.7 b	490.1 ab	3.05 a	4.23 b
T_1 F_3	1463.4 b	22.4 a	448.4 b	3.26 a	5.00 a
LSD	75.8	1.6	67.2	0.67	0.6
T_2 F_1	1511.2 a	20.7 a	494.9 a	3.05 a	4.18 a
T_2 F_2	1382.4 b	16.8 b	467.6 b	2.96 a	3.60 b
T_2 F_3	1311.1 c	17.7 b	439.7 c	2.98 a	4.02 a
LSD	70.2	3.0	27.3	0.22	0.40
T_3 F_1	1223.5 a	13.0 a	470.3 a	2.60 a	2.77 b
T_3 F_2	1111.4 b	14.6 a	441.8 b	2.52 a	3.31 a
T_3 F_3	1055.2 c	14.2 a	412.9 c	2.56 a	3.44 a
LSD	56.1	3.0	28.4	0.41	0.50

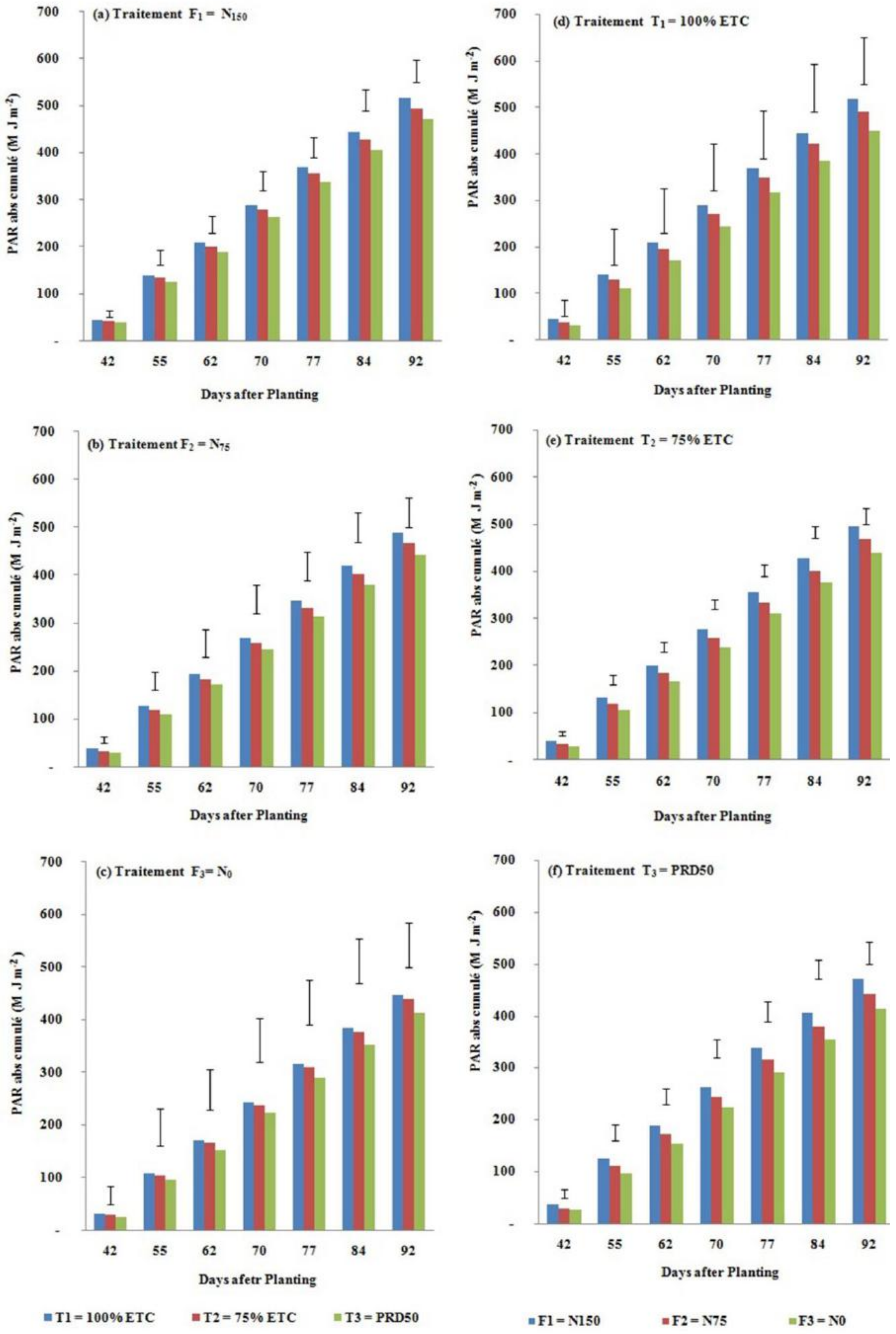

Fig.2: The radiation interception (PAR abs) of potato under the three irrigation treatments (T_1, T_2 and T_3) and the three nitrogen rates (F_1, F_2 and F_3).

ANOVAs analysis (Table 3) affirmed that at final harvest, the RUE_{TDM} and RUE_{GY} were significantly ($P < 0.05$) affected by the irrigation treatment (T_1; T_2 and T_3).

For the three treatments F_1, F_2 and F_3, the highest RUE_{TDM} was recorded respectively under T_1 (2.98; 3.05 and 3.26 g MJ^{-1}) and T_2 (3.05; 2.96 and 2.98 g MJ^{-1}). The lowest was marked under T_3 (2.60; 2.52 and 2.56 g MJ^{-1}). From these results, we can make out that the deficit irrigation T_2 (ETC = 75 %) has no effect on RUE $_{TDM}$. In addition, the Partial Root-Zone Drying Irrigation (PRD_{50}) has led to a reduction in RUE $_{TDM}$. This decline referee against T_1 was equal to (12.7; 17.4 and 21.5%) respectively for the three treatments (F_1; F_2 and F_3).

For RUE_{GY} statistical analysis showed significant ($P < 0.05$) difference between the three irrigation treatments (T_0, T_1 and T_2) for the three nitrogen treatments (F_1; F_2 and F_3).

For the treatment F_1, the highest RUE_{GY} was recorded under the treatment T_2 (4.18 g MJ^{-1}) followed by the treatment T_1 (3.94 g MJ^{-1}). The lowest WUE_{GY} (2.77 g MJ^{-1}) was obtained in treatment T_3.

For the two treatment F_2 and F_3, the maximum RUE_{GY} was marked respectively under the treatment T_1 (4.23 and 5.00 g MJ^{-1}) after that by the treatment T_2 (3.60 and 4.02 g MJ^{-1}). The lowest RUE_{GY} (3.31 and 3.44 g MJ^{-1}) was obtained in treatment T_3. From these consequences, we can concluded that the deficit irrigation T_2 (ETC = 75 %) and the Partial Root-Zone Drying Irrigation (PRD_{50}) has led to a reduction in RUE $_{GY}$. This decrease judge against T_1 respectively for the two treatments (F_2 and F_3) was equal to (14.9 and 21.5%) and (19.6 and 31.2%).

IV. DISCUSSION

The effect of the deficit irrigation and partial root-zone drying irrigation technique (T_1 = 100% ET_C, T_2 = 75% ET_C and T_3 = PRD_{50}) under different nitrogen rate (F_1 = 150 kg N ha^{-1}, F_2 = 75 kg N ha^{-1} and F_3 = 0 kg N ha^{-1}) on the leaf area index (LAI), the Photosynthetically active radiation absorbed (PARabs), the radiation use efficiency for total dry matter production (RUE_{TDM}) and the radiation use efficiency for potato yield (RUE_Y) were studied. The results obtained show that the water deficit negatively influences the evolution of the leaf area index. These results are in agreement with those of Debaeke et al. (1996), Erchidi et al (2000) and Slama et al (2005) who showed that lack of water is reflected in plants by reducing the leaf area by acting on reducing the rate of cell expansion and on the other hand by increasing the rate of leaf senescence. If the plant is under water stress, the stomata are closed to reduce perspiration and water loss. According to Boutraa et al. (2010), the decrease in leaf area can be explained as a method of adapting to water shortage conditions to limit transpiration rate and in order to maintain the water supply in the soil around the roots for increase the chances of survival of the plant. This mechanism is achieved by reducing the elongation of the cell, which leads to the reduction of cell size and consequently the reduction of the leaf area. Thus the results of Sarda et al. (1992) showed that the water deficit decreased the leaf area index and the stomatal conductance of wheat and consequently its photosynthetic capacity.

From the results obtained (figure 2, table 2), it was found that the highest values of PAR abs was recorded at the T_1 treatment for the three nitrogen treatment (F_1, F_2 and F_3). Hence for the total PARabs cumulated at harvest, the T_1 has presented an improvement over the T_3 of 8.9%, 9.8% and 7.9% respectively for the three nitrogen treatments F_1, F_2 and F_3. In fact, the water deficit causes a decrease in PARabs. The application of deficit irrigation reduces the interception of light, which is in agreement with the work of Rezig et al. (2015a), in which they reported that PAR abs decreased from 1041.5 to 907.3 MJ m^{-2} in the wheat crop under water stress conditions. Also, CheikhM'hamed (2015) showed that the decrease in the PARabs cumulated for wheat crop in the I_0 (rainfed) compared to the I_3 (irrigated regime) was in the order of (13, 14 and 11%), respectively for the campaigns (2005-2006, 2006-2007 and 2007-2008). Numerous researchers affirmed that the reduction in the LAI, caused by water deficit and nitrogen deficiency, weaken photosynthetic active radiation (PARabs) and consequently reduce photosynthesis (Gosse et al., 1982, Durand et al. 1991, Akmal and Janssens 2004). Also, the results in table 2 revealed that whatever the water regime (100% ETC, 75% ETC or PRD_{50}) the highest values of PARabs was presented in F_1 treatment then in F_2 and finally in the F_3 treatment. In fact, the F_3 treatment resulted in a reduction of the cumulative PAR abs at harvest relative to F1 of 15.2%, 12.6% and 13.9% respectively for the nitrogen treatments T_1, T_2 and T_3. As a result, the decrease in the nitrogen dose negatively influences the PARabs. Nitrogen plays an important role in the growth of the potato and the deficiency of this element leads to a reduction of the leaf surfaces of the plants and consequently the reduction of the capacity of the plant to intercept the solar radiation. The results obtained are in agreement with those of Dreccer et al. (2000) who observed a reduction in wheat radiation interception under nitrogen deficiency conditions. The results (Figure 3) showed that the water regime (T_1 = 100% ET_C, T_2 = 75% ET_C and T_3 = PRD_{50}) affected negatively the RUE for total dry matter production. The lowest values are recorded at the water treatment T_3 (PRD $_{50}$), hence a reduction with respect to T_1 was equal to 18.3%, 4% and 14.8% respectively for the treatment of nitrogen F_1, F_2 and F_3. Our results are in agreement with those of Rezig et al. (2015a and b) who reported that deficit irrigation reduces the efficiency of light use. In fact, the water deficit negatively affects the development of the leaves (leaf curl, reduction in the number and sizeof leaves, leaf senescence) which causes a reduction in the amount of radiation intercepted and consequently the diminution of the radiation use efficiency.

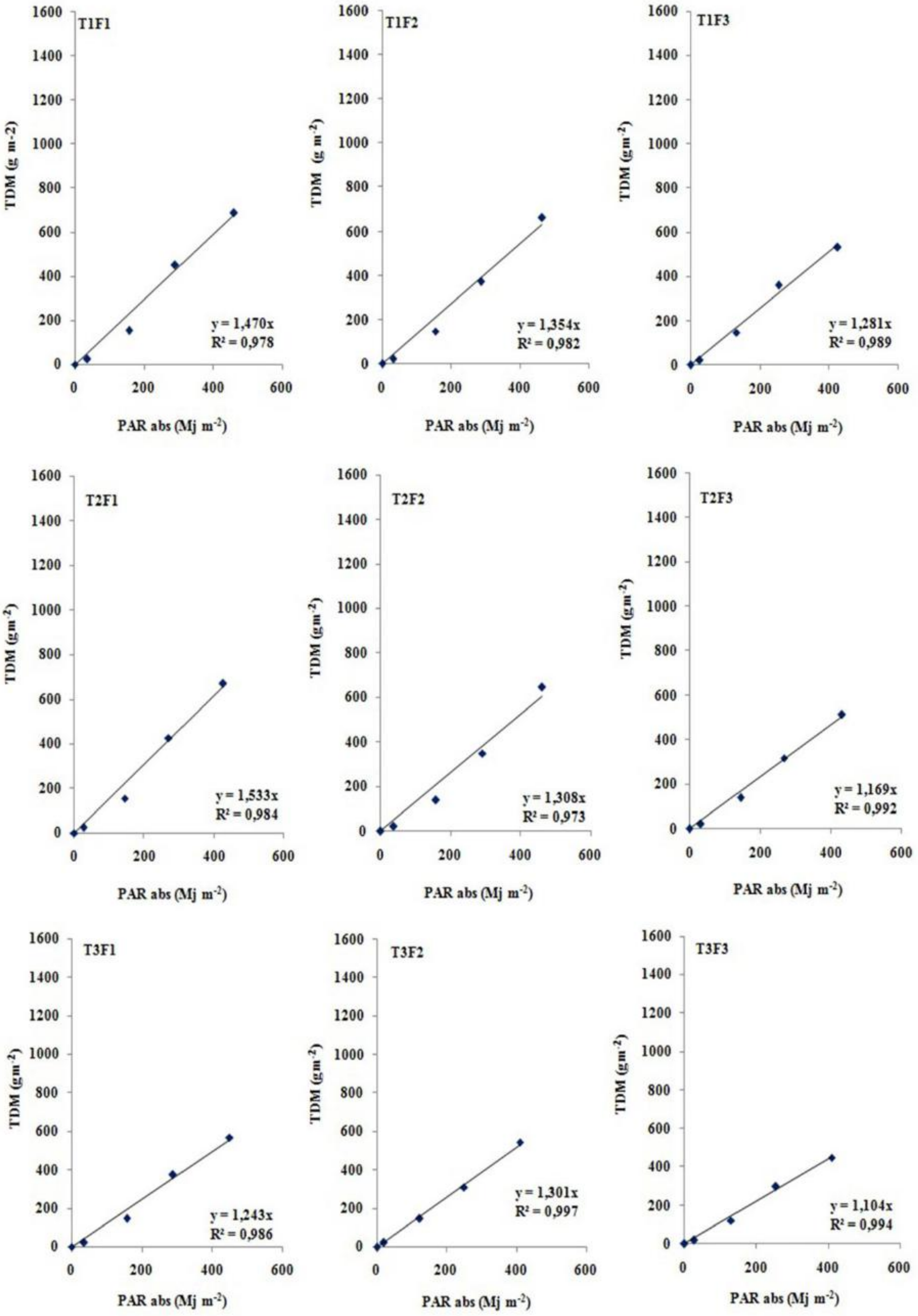

Fig.3: The radiation use efficiency (RUE) of potato under the three irrigation treatments (T_1, T_2 and T_3) and the three nitrogen rates (F_1, F_2 and F_3).

Also, Cornic (2008) showed in the case of soybean that foliar growth is inhibited in drought which causes a decrease in the amount of radiation interception, which leads to a decrease in photosynthetic activity and consequently a decrease in the RUE.The results obtained (figure 3) showed that nitrogen restraint had a negative influence on the RUE regardless of the applied water regime (T_1, T_2 and T_3). In fact, the least values were recorded at the F_3 treatment (where no nitrogen supply was made) from which there is a reduction with respect to F_1 of (14.8%, 30.7% and 11.4%). Similar results have been reported by several researchers (Caviglia and Sadras 2001, Muurinen and Peltonen-Sainio 2006, Stöckle and Kemanian 2009) who attributed the RUE reduction in wheat by lowering the nitrogen dose. Rezig et al. (2015a), have shown that the accumulation of aerial dry matter, PARabs and RUE vary according to the nitrogen regimes applied. Indeed, they increase with enhancing the nitrogen doses. CheikhM'hamed (2015) also found that RUE during the growth cycle was improved by nitrogen fertilization and irrigation. Similarly, Shah et al. (2004) reported that RUE increased from 1.8 to 28 g MJ^{-1} over a range of five nitrogen levels from 0 to 250 kg ha^{-1}. The increase in RUE in high nitrogen rate can be explained in terms of the relationship between leaf nitrogen content and photosynthesis. In plants with low nitrogen content, chlorotic and nitrogen contents in the leaves are reduced. For potato, RUE's response to nitrogen availability has been studied with models that incorporate carbon assimilation of leaves and environmental gradients (Muchow and Sinclair, 1994). Based on these models, Sinclair and Horie (1989) developed the theoretical relationship between RUE and leaf-specific nitrogen as hyperbolic. Indeed, RUE can increase from 1 to 20% in peanut or even more in soybean (Sinclair and Shiraiwa 1993). The availability of water and nitrogen for the plant improves its ability to intercept active photosynthetic radiation and therefore improves the efficiency of light use (Muurinen and Peltonen-Sainio 2006).

V. CONCLUSIONS

From this study, it was demonstrated that the deficit irrigation (DI) has no effect on PARabs. Moreover, the partial root-zone drying irrigation technique (PRD) has led to a reduction in PARabs. The nitrogen deficit affects negatively the PARabs. The deficit irrigation (DI) has no effect on RUE_{TDM}. On the contrary, the partial root-zone drying irrigation technique PRD_{50} has led to a reduction in RUE_{TDM}. The DI and the PRD has led to a reduction in RUE_{GY}. In turn, the use of (DI) from the initiation of tuberization stage to harvest is beneficial compared to full irrigation in terms of improving the radiation use efficiency only for total dry matter production.

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