Effect of Deficit Irrigation and Root-Zone Drying Irrigation Technique under Different Nitrogen Rates on Water Use Efficiency for Potato (*Solanum Tuberosum L.*) in Semi-arid Conditions (I)

Mourad. Rezig, Béchir. Ben Nouna, Sabri Kanzari, Haroun Ben Ammar, Rahma Gatri

Institut National de Recherches en Génie Rural Eaux et Forêts, Tunisie

***Abstract*— *An investigation was carried out at the Technical Center of Potato and Artichoke CTPTA in the region of Saida, located in the lower valley of Medjerda river during the season of 2017. The objective was to evaluate the effects of deficit irrigation (DI) and the root-zone drying irrigation technique (PRD) under different nitrogen rates on total dry matter production (TDM), water consumption (WC) and water use efficiency of potato (Solanum Tuberosum L. VS. Spunta). Three water treatments (T_1 = FI = 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 results showed that the water regime affected negatively the total dry matter accumulation. A decline of 7 and 18.6% was registered in the two treatments T_2 and T_3 compared to the control T_1. The WC decreased during water restriction respectively by 16; 33 and 29% for the T_2 and T_3 (PRD_{50} left) and T_3 (PRD_{50} right) compared to T_1. For the three nitrogen treatments (F_1, F_2 and F_3) the water restriction has increased the WUE. The best values was recorded in the treatment T_2 and then in the treatment T_3 from where this increase compared to T_1 was equal to (22.6% and 12.9%), (24.1% and 12, 4%) and (21.9% and 15.3%) respectively.*

Keywords*— *Deficit Irrigation, Root-Zone Drying Irrigation, Total dry matter, Water consumption, Water Use Efficiency.

I. INTRODUCTION

In Tunisia, the potato occupies an important place in vegetable production, after tomato, watermelon and melon. It represents 12% of total vegetable production. In fact, the potatoes area cultivation has increased from 16800 ha in 1994 to 26200 ha in 2014, making 16% of the vegetables area, which amounts to about 370 thousand tons cultivated. Potato, have elevated water stores and supplemental irrigation is necessary for successful production. However, water availability for agriculture is being reduced as a consequence of global climate change. Therefore, great emphasis was placed on water management for dry conditions based on plant and crop physiology, with the aim of increasing water use efficiency. Deficit irrigation (DI) and partial root-zone drying (PRD) are two irrigation methods that attempt to decrease the agricultural demand for water. PRD is an irrigation technique where by half of the root zone is irrigated while the other half is allowed to dry out (Posadas et al., 2008). The PRD is quite simple, requiring only the adaptation of irrigation systems to allow alternate wetting and drying of parts of the root zone (Loveys et al., 2000). Numerous studies have shown a clear improvement in the water productivity by deficit irrigation (Intrigliolo and Castel. 2005; Goldhamer et al., 2006). In Tunisia, Ben Nouna et al. (2005) and Zairi et al. (2003) have shown that in the case of low and medium climatic demand, deficit irrigation in tomato and potato crops is possible without causing major yield losses. Sadras (2009), confirmed that the use of PRD irrigation and deficit irrigation have allowed a productivity increase of 82% and 76% respectively compared to conventional irrigation with a non-significant reduction in yield. Yang et al., (2011) studied for three years (2006-2008), the water use efficiency of durum wheat under three different irrigation regimes of PRD (30, 40 and 50% of the ETM). The results showed a significant improvement in water productivity from 12 to 71.4%. In fact, the use of PRD irrigation as a very ambitious method of water saving in arid regions of China. Liu et al., (2006) studied the effect of PRD irrigation on the yield and productivity of seasonal potatoes during the tuberization stage. The

https://dx.doi.org/10.22161/ijaers.5.2.4 ISSN: 2349-6495(P) | 2456-1908(O)

results indicated that PRD irrigation led to a significant reduction in yield compared to control with 37% less irrigation water. Shahnazari et al., (2007) indicated that PRD irrigation has improved by 20% the yield of marketable tubers (size 40 to 50 mm) compared to the control. It was concluded in the framework of this study, that PRD irrigation has saved 30% water irrigation and has improved water productivity in seasonal potatoes in the order of 60%. Similar results obtained on the potato and reported by Jovanovic et al, (2010) showed that PRD irrigation led in two successive years to irrigation water saving of the order of 33 and 42% compared to the witness. Several researchers have studied the water use efficiency of potato under PRD conditions (Liu et al., 2006; Shahnazari et al., 2007; Jovanovic et al, 2010; Ben Nouna et al., 2016). However, only few studies concern the effect under different nitrogen rates. Therefore, this study was undertaken to investigate the effects of deficit irrigation and PRD technique under different nitrogen rates on the water consumption and water use efficiency of potato.

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).

Estimation of Crop Potential Evapotanspiration (ETc)

The Reference evapotranspiration (ET_0) was estimated by the software CROPWAT V 8.0 using the FAO-Penman-Monteith approach (Allen et al., 1998). In fact, the climatic data: (1) Daily Minimum and Maximum Temperatures (T_{min} and T_{max}); (2) Daily Relative Humidity (HR); (3) Wind Speed (V) and (4) Rainfall (P) were registered during the three growing seasons from 2009 to 2011 by automatic agro-meteorological station. The Crop Potential Evapotanspiration (ETc) was determined means the following equation:

$$ETc = Kc \times ET0 \quad (1)$$

Plant Material and Experimental Design

Plant material consisted of one potato variety (Solanum tuberosum 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 tuberization 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.

Total Dry Matter Production (TDM) and Tuber Yield (Yd)

The observations were made on above-ground dry matter, tuber dry matter, total dry matter and tuber yield. The sampling was collected for growth analysis at 40, 56, 69, 85 and 96 days after planting Potato (DAPP).

At each date, three plants of potato by plot were collected. All material was dried at 85 °C to constant weight and dry weight was measured. The tuber yield was achieved at 96 DAP.

Irrigation Treatment

Table.1: recapitulated the rainfall and irrigation event during the experiment period for the three irrigation treatments.

DAP	Rain	T_1	T_2	$T_3 = PRD_{50}$	
				Right	Left
12	0	40.7	40.7	40.7	40.7
22	0	46.2	46.2	46.2	46.2
26	2	23.9	23.9	23.9	23.9
34	0	7.5	7.5	7.5	7.5
42	0	7.5	7.5	7.5	7.5
43	0	25	25	25	25
45	0	15	15	15	15
55	0	22.5	16.87	12.2	0
60	0	24.4	18.3	0	12.2
68	0	20	15	10	0

https://dx.doi.org/10.22161/ijaers.5.2.4 ISSN: 2349-6495(P) | 2456-1908(O)

DAP	Rain	T_1	T_2	$T_3 = PRD_{50}$	
69	0	20	15	0	10
75	0	25	18.75	12.5	0
82	0	25	18.75	0	12.5
89	0	25	18.75	12.5	0
96	0	25	18.75	0	12.5
Total	2	352.7	306	213	213

The experimental protocol has begun at 55 days after planting Potato (DAPP). For each start date of the protocol, the irrigation treatments (T_1 = 100% ET_C, T_2 = 75% ET_C and T_3= PRD_{50}) have the same soil moisture conditions. The rainfall observed during the experimental protocol is equal to 2 mm.

For the experiment period, we recorded 15 irrigation events. In fact, FI treatment, has entirely received 352 mm. The T_2 treatment, has completely received 306 mm. The two treatments T_3 (Right side) and T_3 (left side), have received the same dose and it was equal to 213 mm.

Table 1. Rainfall (mm) and irrigation water depth (mm ha^{-1}), for different irrigation treatments (T_1 = 100% ETC, T_2 = 75% ETC and T_3= PRD_{50})

Theoretical Formulations

Estimation of the Daily Water Consumption

The monitoring of soil moisture was carried out on experimental units in order to calculate the water consumption over the entire potato cycle. For the water content measurement, the TDR method was used. For this purpose, we have installed 9 probes in different depths (0-20; 20-40 and 40-60 cm) for each treatments. The initial water stock was determined by the TDR method up to 60 cm for the various experimental units. As well, In each test unit, soil samples were collected every 20 cm to 60 cm deep, and TDR measurements every 20 cm were also carried out to establish the calibration equation.

Water consumption is estimated with soil water balance equation as follows (Hillel, 1998):

$$\mathbf{WC = P + I + U + R - D_W - D_S \ (2)}$$

Where P is the effective precipitation (mm), I is the irrigation (mm), U is the upward capillary flow into the root zone (mm), R is the runoff (mm), D_w was the downward drainage out the root zone (mm) and D_S is the change of soil water stored in soil layer of 0–60 cm (mm). The upward and downward flow was estimated using Darcy's law (Kar et al., 2007; De Medeiros et al., 2005). Results indicated that the two items were insignificant at the experimental site. Runoff was also insignificant during the growing season. Soil water content was measured each month with gravimetrically method. Soil water content data were collected for every 20 cm interval in soil depth. Some measurements were added before and after irrigation.

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

WUE of Total Dry Matter (WUE_{TDM}) and WUE of Tuber yields (WUE_Y) were calculated using the following equations:

$$\mathbf{WUE_{TDM} \ (kg \ m^{-3}) = TDM / WC \ (3)}$$

$$\mathbf{WUE_{GY} \ (kg \ m^{-3}) = GY / WC \ (4)}$$

Where, WUE is the water use efficiency (kg m^{-3}), TDM is the total dry matter production (kg), Y is the tuber yields (kg) and WC is the total water consumption over the whole growing season (m^3).

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 ensemble was completed by multiple comparisons of means with Student Newman Keuls test (S-N-K).

III. RESULTS

Effect of Partial Root-Zone Drying Irrigation (PRD) and Deficit Irrigation (DI) on the Total dry matter (TDM).

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 Total Dry Matter (TDM) of potato was given in figure 1.

For the three water regimes (T_1 = 100% ET_C, T_2 = 75% ET_C and T_3 = PRD_{50}), the effects of three nitrogen rates (F_1, F_2 and F_3) on TDM were represented in (Figure 1a, 1b and 1c). The result showed that from the 56th DAP the TDM of the treatment (F_1) was greater than the two treatments (F_2 and F_3). ANOVA analysis shows that nitrogen application significantly ($P < 0.05$) increased the TDM. The maximum values of potato TDM were achieved in the treatment F_2 and the lowest in F_3. In fact, for the three irrigations regimes (T_1, T_2 and T_3), the maximum amount of TDM was recorded in the treatment F_2 (958.4; 876.5 and 731.4 g m^{-2}) and the lowest in the F_3 (689, 683.2 and 666.4 g m^{-2}). For 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}), the effects of three irrigation regimes (T_1 = 100% ET_C, T_2 = 75% ET_C and T_3 = PRD_{50}) on the total dry matter (TDM) were studied (Figure 1d, 1e and 1f). The results showed that from the 56th day after potato planting

(DAP), the TDM of the treatment T_1 was higher than that in the two treatments (T_2 and T_3). Variance analysis showed a significant effect at (5%) of the water regime on the TDM and the test S-N-K, confirmed that the three treatments (T_1, T_2 and T_3) were statistically heterogeneous. In fact, for the three nitrogen rates (F_1, F_2 and F_3), the maximum amount of TDM was recorded in the irrigation treatment T_1 (941; 958.3 and 722 g m^{-2}), then in T_2 (871.4, 876.5 and 686.3 g m^{-2}) and finally the lowest was marked in the T_3 (765.6, 731.4 and 666.4 g m^{-2}). The combined effect of irrigation regime and nitrogen application has a significant effect ($P < 0.05$) on TDM. So, the maximum value of TDM (TDM max) was recorded in treatment T_1F_2 (958.3 g m^{-2}). The lowest TDM was equivalent to (666.4 g m^{-2}) in treatment T_3F_3.

Effect of Partial Root-Zone Drying Irrigation (PRD) and Deficit Irrigation (DI) on Water Consumption.

Results (figure 2) showed that the daily water consumption of potato was variable during cropping season. Also, we observed that irrigation regimes (T_1, T_2 and T_3) have affected the daily water consumption of potato during tuberization stage. The water consumption in the treatment (T_1) was higher than that in the two treatments (T_2 and T_3). For the T_1F_1 (Figure 2.a), the curve which represents the daily evolution of ETR and ETC followed the same paces and was exactly superimposed. In fact, during the all growing cycle of potato the ETR and ETC was equal to 371 mm. Similarly, for the T_2F_1 treatment (Figure 2.b), the ETR and the ETC have the same rate until the 56^{th} DAP, and after this date the daily ETR becomes lower than the daily ETC. In detail, the cumulative ETR in T_2F_1 regime was 310 mm (from planting to harvest) and the cumulative ETC was 371 mm. In result, the deficit of water needs (ETR compared to ETC) was 61 mm and was observed from 56 DAP to 89 DAP. For the T_3F_1 treatment (Right side), the ETR and the ETC were equal (Figure 2.c) until the 56^{th} DAP, and after this date the daily ETR come to pass lower than the daily ETC. In circumstances, the cumulative ETR in T_3F_1 regime (Right side) was 248 mm (from planting to harvest). The deficit of water needs (ETR compared to ETC) was 123 mm and was registered from 56 to 67 DAP and from 78 to 100 DAP. For the T_3F_1 treatment (Left side), the ETR and the ETC were equivalent (Figure 2.d) until the 56^{th} DAP, and after this day the daily ETR becomes inferior to the daily ETC.

In indicate, the cumulative ETR in T_3F_1 regime (Left side) was 260 mm (from planting to harvest). In effect, the deficit of water needs (ETR compared to ETC) was 111 mm and was marked since the middle of the season (from 50 to 68 DAP and from 78 to 100 DAP). The results obtained showed that the water consumption of the potato crop under water restriction conditions decreased respectively by 16 and 33% and 29% for T_2 and T_3 (PRD 50 left) (PRD 50 right) compared to the control treatment T_1.

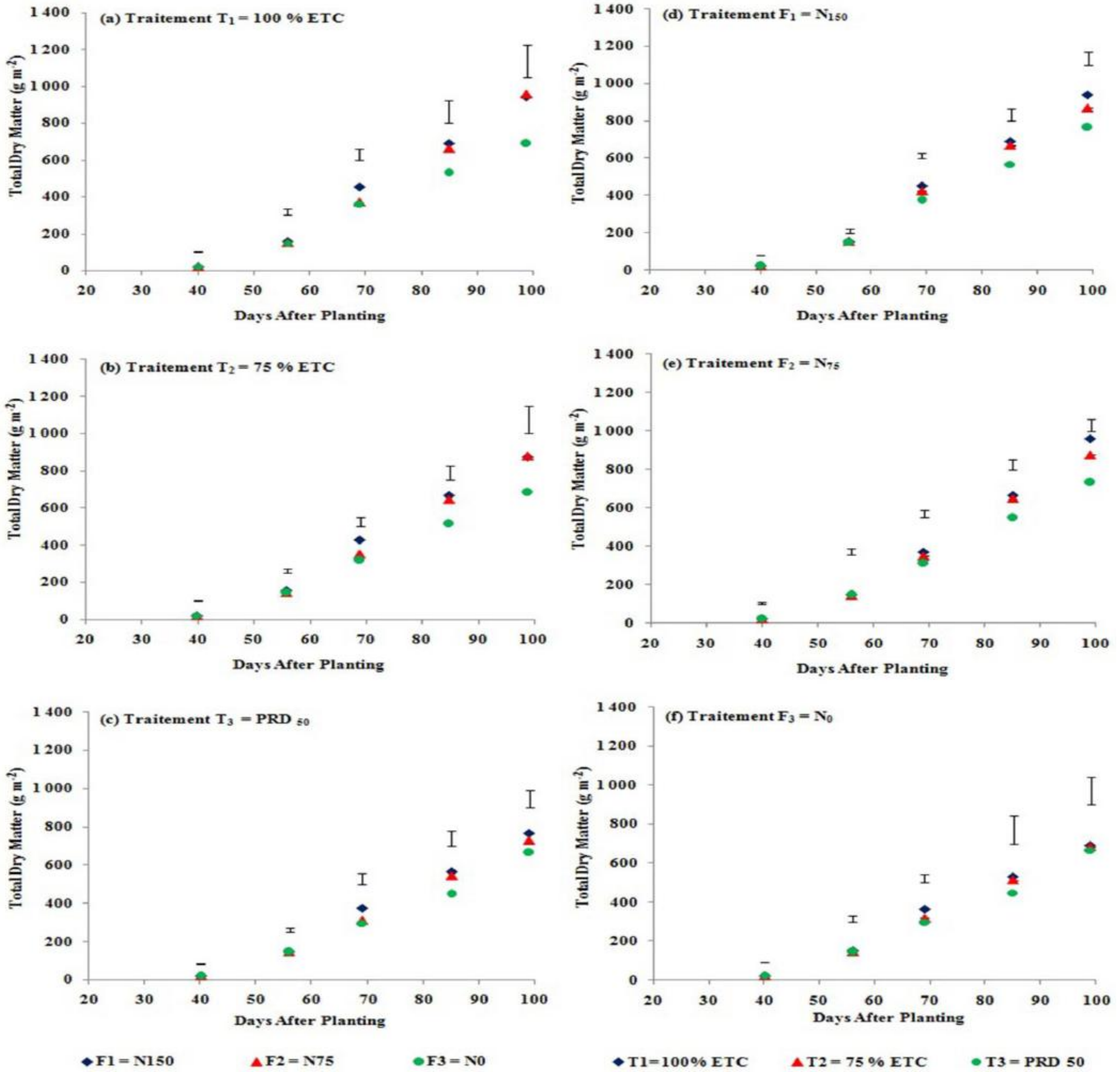

Fig.1: the Total dry matter (TDM) of potato under the three irrigation treatments (a, b and c) and the three nitrogen rates (d, e and f).

https://dx.doi.org/10.22161/ijaers.5.2.4 *ISSN: 2349-6495(P) | 2456-1908(O)*

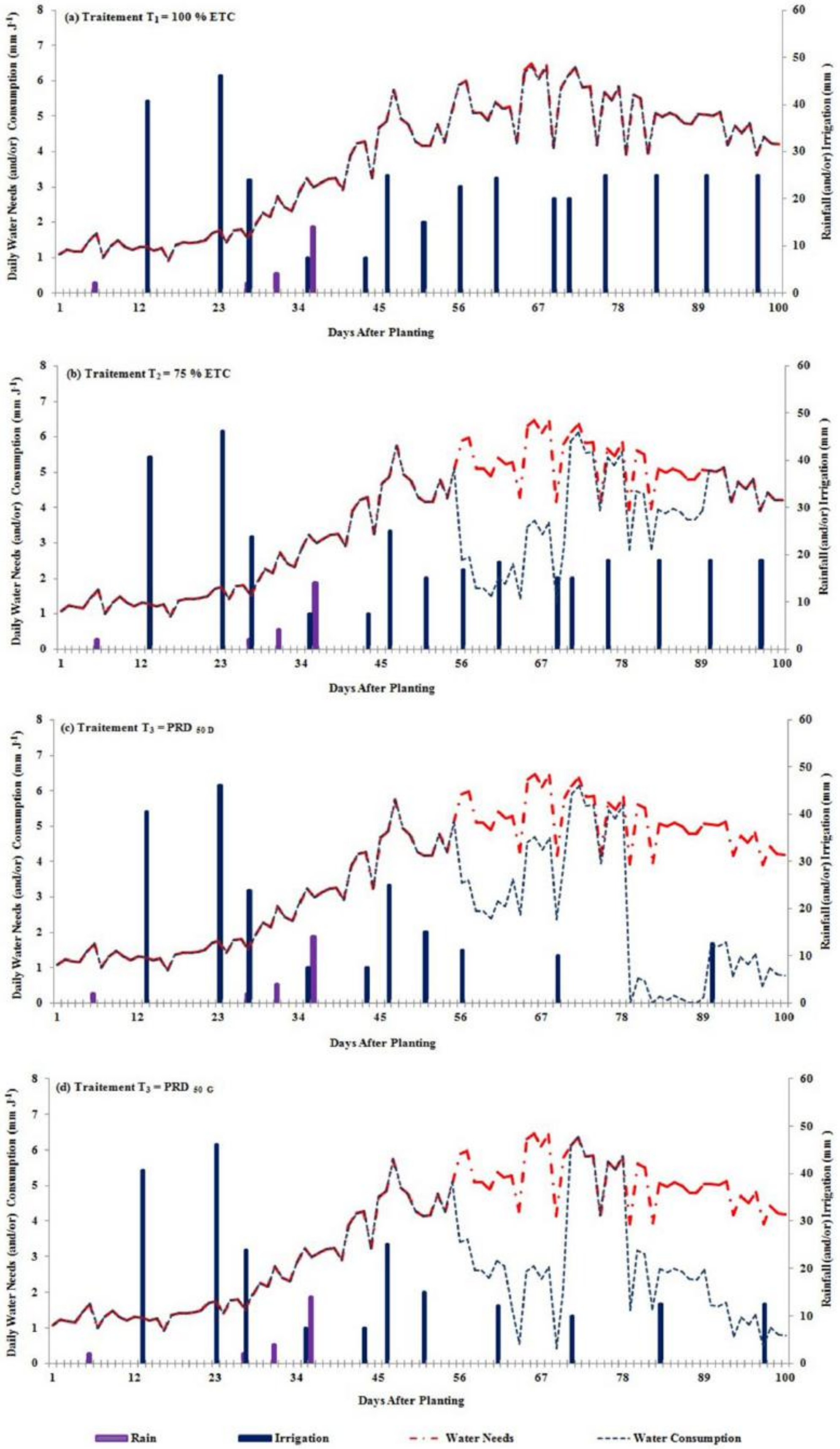

Fig.2: The daily water Needs and Consumption by potato under the three treatments (T_1, T_2, and T_3)

https://dx.doi.org/10.22161/ijaers.5.2.4 ISSN: 2349-6495(P) | 2456-1908(O)

Effect of Partial Root-Zone Drying Irrigation (PRD) and Deficit Irrigation (DI) on Water Use Efficiency.

The effect of three irrigation treatments (T_1, T_2 and T_3) and the three nitrogen rates (F_1, F_2 and F_3) in the water use efficiency (WUE) of potato was given in Figure 3.

The relation between the water consumption and the total dry matter production over all potato growing season and under the nine treatments is given in Figure 3. From these results, we observed toward different treatments that the total dry matter production increased linearly with the cumulative water consumption. The slope of this regression is the conversion efficiency of water consumption into total dry matter production (WUE). Similarly, we noted that, the highest amount of WUE was recorded in the T_2 treatment (3.9; 3.7 and 2.9 kg m^{-3}) and after that in T_3 (3.5; 3.2 and 2.7 kg m^{-3}). However, the least was recorded in the T_1 treatment (3; 2.8 and 2.3 kg m^{-3}). In detail, for the three nitrogen rate (F_1, F_2 and F_3) the water use efficiency in T_2 and T_3 has illustrated respectively an increased of (23.1; 24.3 and 20.7%) and (14.3; 12.5 and 14.8 %) compared to T_1. Statistical analysis showed that the WUE was significantly ($P< 0.05$) affected by irrigation doses (T_1, T_2 and T_3) for three nitrogen rates.

The water use efficiency of total dry matter production at harvest (WUE_{TDM}) and the water use efficiency of yield (WUE_{GY}) of the nine treatments were exposed in Table 2.

Table.2: water use efficiency (kg m^{-3}) of total dry matter at harvest (WUE_{TDM}) and water use efficiency (kg m^{-3}) of yield (WUE_{GY}) under the nine treatments.

Trait	TDM	Yield	WUE_{TDM}	WUE_{YD}
T_1F_1	1539.29 a	20.35 a	4.15 b	5.49 b
T_2F_1	1511.16 a	20.73 a	4.87 a	6.67 a
T_3F_1	1223.49 b	13.01 b	4.92 a	5.24 b
LSD	88.02	1.5	0.29	0.45
T_1F_2	1493.73 a	20.73 a	4.03 b	5.59 ab
T_2F_2	1382.38 b	16.84 b	4.45 a	5.43 b
T_3F_2	1111.41 c	14.64 c	4.47 a	5.89 a
LSD	28.62	3.4	0.19	0.49
T_1F_3	1463.38 a	22.04 a	3.95 c	5.94 a
T_2F_3	1311.15 b	17.67 b	4.71 a	5.69 a
T_3F_3	1055.17 c	14.21 c	4.25 b	5.72 a
LSD	132.78	3.07	0.28	1.31

TDM: Total dry matter (g m^{-2}), GY: potato yield (t ha^{-2}), LSD: Least Significant Difference (5%).

ANOVAs analysis (Table 2) confirmed that at harvest, the WUE_{TDM} and WUE_{GY} were significantly ($P < 0.05$) affected by the irrigation treatment (T_1; T_2 and T_3).

For the two treatments F_1 and F_2, the uppermost WUE_{TDM} was registered respectively under T_3 (4.92 and 4.47 kg m^{-3}) and next to in T_2 (4.87 and 4.45 kg m^{-3}). The lowest was observed under T_1 (4.15 and 4.03 kg m^{-3}). However, for the treatment F_3, the highest WUE_{TDM} was registered in the T_2 (4.71 kg m^{-3}) and then in T_3 (4.25 kg m^{-3}). The lowly was observed under T_1 (3.95 kg m^{-3}).

Nevertheless, for WUE_{GY} statistical analysis showed significant ($P < 0.05$) difference between the three treatments (T_0, T_1 and T_2) only under F_1 and F_2. For the treatment F_1, the highest WUE_{GY} was recorded under the treatment T_2 (6.67 kg m^{-3}) followed by the treatment T_1 (5.49 kg m^{-3}). The lowest WUE_{GY} (5.24 kg m^{-3}) was obtained in treatment T_3. Conversely, for the treatment F_2, the maximum WUE_{GY} was marked under the treatment T_3 (5.89 kg m^{-3}) after that by the treatment T_1 (5.59 kg m^{-3}). The lowest WUE_{GY} (5.43 kg m^{-3}) was obtained in treatment T_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 total dry matter production (TDM), the water consumption (WC), the potato yield (Y), the water use efficiency for total dry matter production (WUE_{TDM}) and the water use efficiency for potato yield (WUE_Y) were studied.

https://dx.doi.org/10.22161/ijaers.5.2.4 *ISSN: 2349-6495(P) | 2456-1908(O)*

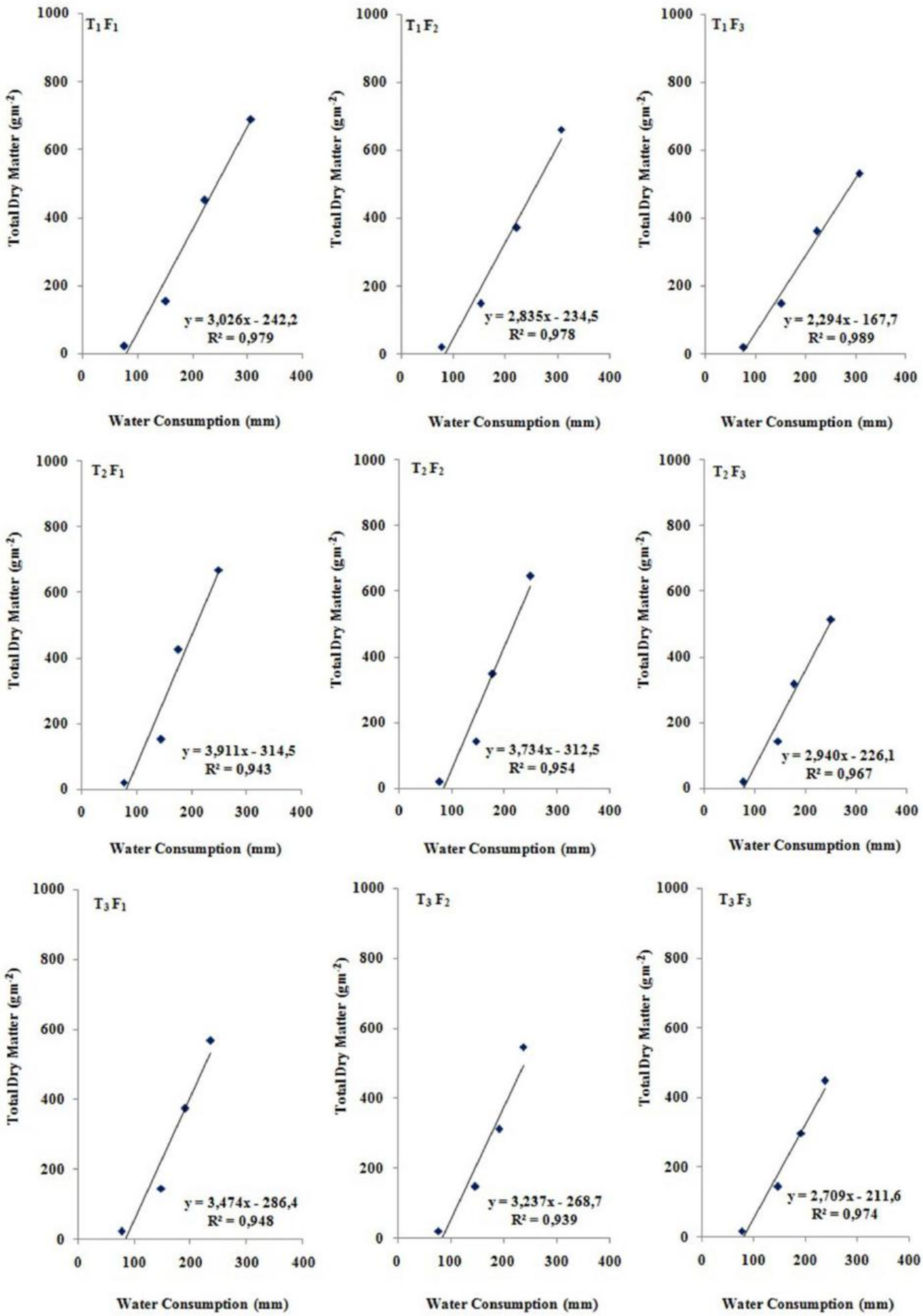

Fig.3: The water use efficiency (WUE) of potato under the three irrigation treatments and the three nitrogen rates).

As illustrated by the outcome in (Figure 1a, 1b and 1c) that for the three irrigation regimes, the nitrogen fertilization affected the accumulation of total dry matter. Hence the accumulation of dry matter is positively

https://dx.doi.org/10.22161/ijaers.5.2.4 ISSN: 2349-6495(P) | 2456-1908(O)

correlated with the nitrogen application. Indeed, these results are in agreement with those found by Ali et al., (2009), Massignam et al., (2011) and Hamzei (2011), who observed that increased nitrogen improved the biological yield of crops. Similarly, MacDonald (2002) investigated the effect of different nitrogen doses on the yield of several varieties of durum wheat, and observed that TDM at the anthesis stage increased significantly with increasing nitrogen rate. Latiri-Souki, (1994) mentioned that the rate of nitrogen uptake during durum wheat development is linearly related to the development of total dry matter. Moreover, Cheikh M'hamed et al., (2014) showed that the application of nitrogen in N_1 (150 kg N ha^{-1}) and N_2 (100 kg N ha^{-1}) significantly ($P < 0.001$) increased the MST compared to N_3 (50 kg N ha^{-1}) and N_4 (0 kg N ha^{-1}). Indeed, treatment N_1 improved the MST relative to N_3 and N_4 under the three water regimes D_1 (100% ETC), D_2 (70% ETC) and D_3 (40% ETC). Sanaa (1998) reported that controlled nitrogen fertilization (150 or 300 kg N / ha) increased the dry matter content of leaves and stems compared with the unfertilized control.

The same result was reported by Golli (1992) who showed that by increasing nitrogen doses from (0 to 250 kg N ha^{-1}), the cumulative aerial dry matter increased from (16.8 to 48.9 g $plant^{-1}$). Also, Ben Ammar (2007) found that the biomass accumulated at the potato beginning cycle in the 3 nitrogen treatments was the same up to 58 JAP. Then, a difference was observed between the treatments N_1 (15 t ha^{-1}), N_2 (30 t ha^{-1}) and N_0 (without addition of N). Hence, the maximum accumulated biomass was 0.62; 1.06 and 1.32 t ha^{-1} respectively at the N_0, N_1 and N_2 treatments. Also, according to Shah et al. (2004) MST increased from 1442 to 2131 g m^{-2} in the treatment with a high nitrogen content compared to the treatments with low nitrogen content.

The results (Figure 1d, 1e and 1f) showed that the water regime (T_1 = 100% ET_C, T_2 = 75% ET_C and T_3 = PRD_{50}) affected negatively the total dry matter accumulation. A reduction of 7 and 18.6% was recorded in the two treatments T_2 and T_3 compared to the control T_1. Indeed, these results are in agreement with those of Rezig et al. (2015 a and b); Cheikh M'hamed et al. (2014 and 2015). These authors studied the effects of deficit irrigation in wheat and potato crops and showed that the water stress affected the accumulation of total dry matter. According to Rousselle et al. (1996), water stress also influenced tuberization by reducing the number of tubers formed. A water deficit during the tuber growth phase can influence vegetative growth and reduce leaf coverage irreversibly (Deunier et al. 1997). In addition, a lack of water causes the closure of stomata, which results in a rise in leaf temperature, a reduction in photosynthetic activity and consequently a decrease in yield (Rousselle et al., 1996). Similarly, Ben Nouna et al. (2016) reported that for the four water regimes (FI, PRD_{80}, PRD_{70} and PRD_{60}) the dry matter production increases linearly with the cumulative water consumption.

The obtained results in figure 2 showed that the water consumption decreased through water restriction respectively by 16; 33 and 29% for the T_2 and T_3 (PRD_{50} left) and T_3 (PRD_{50} right) compared to with the control treatment T_1. This feedings are in agreement with those of Rezgui et al. (2005); Rezig et al (2015 a and b) and Cheikh M'hamed et al. (2014 and 2015) for wheat. As well, for potato, Ben Nouna et al (2016) found that the cumulative water consumption was marked a reduction of 12.6; 17.9 and 25.1% respectively for the treatments PRD_{80}, PRD_{70} and PRD_{60} compared to the control FI. These authors have shown that the water deficit significantly decreases water consumption.

The results (figure 3) showed that the water restriction has led to an increase in the WUE at any rate of the nitrogen supplied (F_1, F_2 and F_3). The best values was recorded in the treatment T_2 and then in the treatment T_3 from where this increase compared to T_1 was equal to (22.6% and 12.9%), (24.1% and 12, 4%) and (21.9% and 15.3%) respectively for the three nitrogen treatments (F_1, F_2 and F_3). Our results consent with those of Ben Nouna et al. (2016) who showed that PRD_{60} treatment improved the WUE of potato by (10.9 and 10.2%) and (25.8 and 19.7%) compared to full irrigation and PRD_{80}. Also, Saeed et al. (2008) found that PRD irrigation used 29% less water and improved the WUE by 19%. Similarly, Xie et al. (2012) reported that the PRD_{50} treatment used 50% less water and increased the WUE by 48%. Several studies have indicated that deficit irrigation increased the WUE of wheat, potato, maize and rice. Indeed, moderate water stress induces partial stomatal closure, which would lead to an improvement in WUE (Turner, 1997). Ahmadi et al. (2010b) investigated the effect of PRD irrigation on seasonal potatoes, based on soil texture. They found that PRD irrigation resulted in a significant increase in water productivity in seasonal potatoes of 11% for sandy soil and 36% for sandy loam soil. Zairi et al. (2000) proved for wheat and potato that the better water productivity was obtained for the treatments carried out with the ETM. For potato, the consumption efficiency varied from 11.2 (a severe water stress) to 20.1 kg m^{-3} (an unstressed treatment).

From the results in table 2, the variance analysis showed a significant effect at (5%) of water treatment on the WUE_{TDM} at harvest. Indeed, the T_3 treatment presented the highest values of the WUE_{TDM} for the three nitrogen treatment. In fact, at the level of the T_3 water treatment, an increase in the WUE_{TDM} of 15.7%, 9.8% and 7% compared to T_1 for the three nitrogen treatments F_1, F_2 and F_3 respectively. The water restriction led to an increase in the WUE_{TDM}. Our results show that deficit irrigation improved the water use efficiency of total dry matter at the end of the cycle which is in total accordance with the studies of Kirda et al., 2004. These showed that there is no significant difference between the WUE_{TDM} in the PRD and the DI. At the level of nitrogen treatment F_1 (Table 2), the T_2 showed a significant increase in the WUE_{GY}, from which we have 6.67 kg m^{-3} compared to 5.49 kg m^{-3} in the T_1. This is can be explained by a decrease of 16.26% in the water consumption in_the T_2 compared to T_1. Although variance analysis showed no significant difference between the T_1 and T_3 treatments in the WUE_{GY}, we note that, the decrease in water consumption has led to a significant reduction in yield which was equal to 36% compared to T_1. Similarly, we observed that at the F_2 nitrogen treatment, the T_3 had the highest WUE_{GY}, despite the 29.4% decrease in yield compared to T_1, which is explained by the decrease in the water consumption from 370 mm in the T_1 to 248 mm in the T_3. For F_3 treatment, variance analysis showed no significant differences at (5%) between water treatments. Indeed, the decrease in water consumption has led to a significant reduction in yield. The obtained results show that the deficit irrigation applied at the tuberization stage makes it possible to increase the WUE_{GY}. Thus, these results are in agreement with those of Li et al. (2005), Rezig et al. (2015b) who reported that the WUE for tuber yield increased by decreasing the irrigation dose. Ben Nouna et al. (2016) also showed that the WUE_{GY} was higher in PRD60 than in FI treatments; PRD_{80} and PRD_{70}.

V. CONCLUSION

In the conditions of this study, we were able to assume, that the deficit irrigation (DI) and the partial root-zone drying irrigation technique (PRD) were two prospective water-saving irrigation strategies, especially for the drought sensitive crop such as potatoes and with restricted water conditions. During the all cropping potato cycle, the water restriction has improved WUE. The best values was recorded in the treatment T_2 and then in the treatment T_3. Similarly at harvest, for the two treatments F_1 and F_2, the highest (WUE_{TDM}) was registered under T_3 and then in the T_2. The lowest was observed under T_1. However, for the treatment F_3, the maximum WUE_{TDM} was registered in the T_2 and after that in T_3. Even so, for WUE_{GY} statistical analysis showed significant ($P < 0.05$) difference between the three treatments (T_0, T_1 and T_2) only under F_1 and F_2. For the treatment F_1, the highest WUE_{GY} was recorded under the treatment T_2 followed by the treatment T_1. Conversely, for the treatment F_2, the maximum WUE_{GY} was marked under the treatment T_3 after that by the treatment T_1. In turn, the use of DI and PRD with 50% of Etc from the initiation of tuberization stage to harvest is advantageous compared to full irrigation in terms of improving the water use efficiency.

ACKNOWLEDGEMENTS

National Research Institute of Rural Engineering, Water and Forestry (INRGREF), Technical Center of the Potato and Artichoke (CTPTA) is acknowledged for providing all needed materials for conducting this study.

REFERENCES

[1] Ahmadi, S.H., Andersen, M.N., Plauborg, F., Poulsen, R.T., Jensen, C.R., Sepaskhah, A.R., Hansen, S., 2010a. Effects of irrigation strategies and soils on field grown potatoes: Gas exchange and xylem [ABA]. Agricultural Water Management, 97: 1486-1494.

[2] Ahmadi, S.H., Andersen, M.N., Plauborg, F., Poulsen, R.T., Jensen, C.R., Sepaskhah, A.R., Hansen, S (2010 b). Effects of irrigation strategies and soils on field grown potatoes: Yield and water productivity. Agri. Water Management. DOI:10.1016/j.agwat.2010.07.007.

[3] Ali, M.A., Aslam, M., Hammad, H.M., Abbas, G., Akram, M. & Ali, Z., 2009. Effect of nitrogen application timings on wheat yield under that environment. J. Agric. Res. 47(1): 31-35.

[4] Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration: guidelines for computing crop water requirements. In: United Nations FAO, Irrigation and Drainage Paper 56. FAO, Rome, Italy.

[5] Ben Ammar. H., (2007). Analyse de la croissance et du développement de la pomme de terre de primeur et des cinétiques d'exportation en élément NPK : pour un meilleur raisonnement de la fertilisation azotée. Mémoire de mastère. Institut National Agronomique de Tunisie.105p.

[6] Ben Nouna B., Zairi A., Ruelle P., Slatni A., Yacoubi S., Ajmi T et Oueslati T. 2005. Evaluation de la demande en eau et pilotage de l'irrigation déficitaire des cultures annuelles : Exemple de méthodologie et outils de mesure utilisables. Actes du Séminaire «Modernisation de l'agriculture irriguée dans les pays du Maghreb ». Rabat du 19-23 Avril 2004 pp.

[7] Ben Nouna B., Ben Ammar H., Hanafi S. Elamami H., Faidi Sana et Ghribi R. 2014. Effet de la technique d'irrigation par assèchement partiel de la zone racinaire sur la productivité de la pomme de terre de saison. Actes du séminaire international " Gestion durable des ressources en eau et en sols : Situation, Défis et Perspectives. 19-20 novembre 2013 Hammamet. Annales de l'INRGREF, Numéro spécial (19, 2014).

[8] Ben Nouna B, Rezig M., Bahrouni., H & Ben Ammar H. 2016. Effect of Partial Root-Zone Drying Irrigation Technique (PRD) on the Total Dry Matter, Yield and Water Use Efficiency of Potato under

Tunisian Semi-Arid Conditions. Journal of Agricultural Science; Vol. 8 (7); 129-141.doi:10.5539/jas.v8n7p129

[9] Cheikh M'hamed H., Rezig M, Ben Naceur M. 2014. Deficit Irrigation of Durum Wheat (Triticum durum Desf): Effects on Total Dry Matter Production, Light Interception and Radiation Use Efficiency under Different Nitrogen Rates. Sustainable Agriculture Research; Vol. 4(1); 26-40.

[10] Cheikh M'hamed H., Rezig M, Ben Naceur M. 2015. Water Use Efficiency of Durum Wheat (Triticum durum Desf) under Deficit Irrigation. Journal of Agriculture Science; Vol.7(8). 238-249

[11] Cheikh M'Hamed H., 2016. Etude de l'efficience de l'utilisation de l'eau et de la lumière du blé dur (Triticum durum Desf., Var. Karim) conduit sous différents régimes hydriques et azotés. Thèse de doctorat de l'INAT.

[12] Deunier J., Gravoueuille J., Gaucher D., Largnier M., Martin M., Bassez J. et Pouprd F. 1997. Pomme de terre, Irrigation. ITCF, Paris.

[13] Goldhamer DA, Viveros M.,Salinas M., 2006. Regulated deficit irrigation in almonds: effects of variations in applied water and stress timing on yield and yield components. Irrig Sci (2006) 24: 101–114. DOI 10.1007/s00271-005-00148.

[14] Golli H. (1992). Effets de l'azote sur la croissance végétative, la tubérisation et la nutrition azotée de la pomme de terre de primeur. Mémoire de fin d'étude de cycle ingénieur. Ecole Supérieure d'Horticulture, Chott Mariem Sousse. 51p

[15] Hamzei, J., 2011. Seed, oil, and protein yields of canola under combinations of irrigation and nitrogen application. Agron. J. 103: 1152-1158.

[16] Intrigliolo D. S. and J. R. Castel. 2005. Effects of regulated deficit irrigation on growth and yield of young Japanese plum trees. Journal of Horticultural Science & Biotechnology. 80 (2) 177–182. DOI: 10.1080/14620316.2005.11511913.

[17] Jovanovic, Z., Stikic, R., Vucelic-Radovic, B., Paukovic, M., Brocic, Z., Matovic, G., Rovcanin, S., Mojevic, M (2010). Partial root-zone drying increases WUE, N and antioxidant content in field potatoes. European Journal of Agronomy 33,124–131. DOI:10.1016/j.eja.2010.04.003.

[18] Latiri-Souki, K., 1994. Analysis of the effects of water and nitrogen supply on the yield and growth of durum wheat under semi-arid conditions in Tunisia. PhD Thesis, University of Reading. UK. 180 p.

[19] Latiri-Souki, K., Nortcliff, S. & Lawlor, D.W., 1998. Nitrogen fertilizer can increase dry matter, grain production and radiation and water use efficiencies for durum wheat under semi-arid conditions. European Journal of Agronomy. 9: 21-34.

[20] Liu, F., Shahnazari, A., Andersen, M.N., Jacobsen, S.E., Jensen, C.R (2006) Effects of deficit irrigation (DI) and partial root zone drying (PRD) on gas exchange, biomass partitioning, and water use efficiency in potato. Scientia Horticulture, 109:113–117. DOI:10.1016/j.scienta.2006.04.004

[21] Loveys, B. R., Stoll, M., Dry, P. R., & McCarthy, M. G. 2000. Using plant physiology to improve the water use efficiency of horticultural crops. Acta Horticulturae, 537, 187-197. http://dx.doi.org/10.17660/ActaHortic.2000.537.19

[22] MacDonald, G.K., 2002. Effects of nitrogenous fertilizer on the growth, grain yield and grain protein concentration of wheat. Aust. Journal of Agronomy Research. 43(5): 949-967.

[23] Massignam, A.M., Chapman, S.C., Hammer, G.L., & Fukai, S., 2011. Effects of nitrogen supply on canopy development of maize and sunflower. Crop Pasture Sci. 62: 1045- 1055.

[24] Posadas, A., Rojas, A., Malaga, M., Mares, V., Quiroz, R.A., 2008. Partial root-zone drying: an alternative irrigation management to improve the water use efficiency of potato crops, Production Systems and the Environment Division Working Paper No. 2008-2. International Potato Center, p. 14.

[25] Rezgui M., Zairi A., Bizid E., Ben Mechlia N. 2005. Consommation et efficacité d'utilisation de l'eau chez le blé dur (Triticum durum Desf.) cultivé en conditions pluviales et irriguées en Tunisie. Cahiers Agricultures vol. 14, n° 4. 391-397.

[26] Rezig, M., Sahli, A., Hachicha, M., Ben jeddi, F. & Harbaoui, Y., 2013a. Potato (Solanum tuberosum L.) and Bean (Phaseolus vulgaris L.) in Sole Intercropping: Effects on Light Interception and Radiation Use Efficiency. Journal of Agricultural Science. 5(9): 65-77.

[27] Rezig, M., Cheikh M'hamed, H., Ben Naceur, M., 2015b. Durum Wheat (Triticum durum Desf): Relation between Photosynthetically Active Radiation Intercepted and Water Consumption under Different Nitrogen Rates. Journal of Agricultural Science; Vol. 7 (8); 225-237. doi:10.5539/jas.v7n8p225

[28] Rousselle P., Robert Y., Corsnier J.C. 1996. La pomme de terre production, amélioration, ennemis, et maladie. INRA Paris.

[29] Sadras, V.O., 2009. Does partial root-zone drying improve irrigation water productivity in the field? A meta analysis. Irrigation Science, 27: 183-190. DOI: 10.1007/s00271-008-0141-0.

[30] Saeed, H., Grove, I. G., Kettlewell, P. S., & Hall, N. W. (2008). Potential of partial root zone drying as an alternative irrigation technique for potatoes (Solanum tuberosum). Annals of Applied Botany, 152, 71-80.

https://dx.doi.org/10.22161/ijaers.5.2.4 *ISSN: 2349-6495(P) | 2456-1908(O)*

[31] Sanaa. M., (1998). Effets de l'azote sur la culture de pomme de terre. Revue INAT. Vol 4 N° 2. pp 4-6.

[32] Shah, S. F. A.; McKenzie, B. A.; Gaunt, R. E.; Marshall, J. W.; Frampton, C. M. 2004: Effect of early blight (Alternaria solani) on healthy area duration and healthy area absorption of potatoes (Solanum tuberosum) grown in Canterbury, New Zealand with different nitrogen application and stress from potato cyst nematode (Globodera rostochiensis). New Zealand Journal of Crop and Horticultural Science 32: 85-102.

[33] Shahnazari, A., Liu, F., Andersen, M.N., Jacobsen, S.E., Jensen, C.R .2007. Effects of partial root-zone drying on yield, tuber size and water use efficiency in potato under field conditions. Field Crops Research, 100: 117- 124. DOI: 10.1016/j.fcr.2006.05.010

[34] Turner, N.C., 1997. Further progress in crop water relations. Advances in Agronomy. 58:293-338

[35] Xie, K., Wang, X.-X., Zhang, R., Gong, X., Zhang, S., Mares, V., Quiroz, R. 2012. Partial root-zone drying irrigation and water utilization efficiency by the potato crop in semi-arid regions in China. Scientia Horticulturae, 134, 20-25.

[36] Yang CH, Huang GB, Chai Q, Luo ZX (2011) Water use and yield of wheat/maize intercropping under alternate irrigation in the oasis field of northwest China. Field Crops Research 124: 426-432. DOI: 10.1016/j.fcr.2011.07.013.

[37] Zairi A., Ben Nouna B., Ruelle P., Nasr Z., Oueslati T. Ajmi T., 2000. Irrigation et effet du déficit hydrique sur les productions : cas du blé et de la pomme de terre. Actes du séminaire "Economie de l'eau en irrigation", Hammamet – Tunisie : 14-16 Novembre 2000. Numéro spécial des Annales de l'INRGREF, 93-113.

[38] Zairi, A., El Amami, H., Slatni, A., Pereira, L.S., Rodriguez, P.N., Machado, T. 2003. Coping with drought: deficit irrigation strategies for cereals and field horticultural crops in Central Tunisia. In: G. Rossi, A. Cancelliere, L.S. Pereira, T. Oweis, M. Shatanawi, A. Zairi (Eds.) Tools for Drought Mitigation in Mediterranean Regions. Kluwer, Dordrecht, pp. 181-201.