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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

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Abstract

Three field experiments were conducted in the plot of Technical Centre for Potato and Artichoke during three cropping season 2009, 2010 and 2011.The objective of this research is to evaluate the effect of the partial root-zone drying irrigation technique (PRD) on the dry matter, yield, water consumption and water use efficiency of potato (Spunta Variety). Four treatments were applied from the initiation of tuberisation stage to potato harvesting: FI treatment received 100% of Etc; PRD_{80}, PRD_{70}, and PRD_{60} treatments received respectively: 80, 70 and 60% of FI at each irrigation event and it was shifted between the two sides of the plants every 2 to 10 days. The highest water consumption was observed in FI as 336.5, 376, and 341.8 mm in the 2009, 2010 and 2011 respectively, and the lowest was found in PRD_{60} as 280.4, 294.5, and 256.1 mm in the 2009, 2010 and 2011 respectively. The maximum tuber yield was obtained from the FI as 25.6, 42.9 and 39.1 tha^{-1}, in the 2009, 2010 and 2011 respectively. There was no significant difference between FI and PRD_{60} with respect to tuber yields (LSD 5%).The highest water use efficiency (WUE_Y) was found in PRD_{60} as 13.4 kg m^{-3}, in the second experiment (2010) and the lowest was found in PRD_{80} as 6.8 kg m^{-3} in the first experiment (2009). In the other hand, a linear relation between the accumulated total dry matter and the accumulated water consumption was able to be revealed.

Keywords: partial root-zone drying, drip irrigation, water use efficiency, dry matter, yield, potato

1. Introduction

More than 9 billion people will inhabit the Earth by 2050 with limited land and water resources. Faced to this challenge; How to boost the productivity in the Irrigated Agricultural Sector? The productivity of irrigated crop yield should be increased by 40% in order to meet rising the demand of growing population (Lascano & Sojka, 2007). Around 70% of the total water withdrawals and 60-80% of total consumptive water use are consumed in irrigation (Huffaker & Hamilton, 2007). In Tunisia, 83% of mobilized water resources are used for irrigation (DGEDA, 2012). Water saving is needed, firstly to deal with competition between sectors of potable and industrial water and also to ensure the sustainability of irrigation schemes. The conventional irrigation (based on the needs of maximum crop evapotranspiration) is used by farmers in the limited water availability conditions or not limited. This irrigation method is classified nowadays as a luxury water use and which can be optimized with or without a decrease in yield (Kang & Zhang, 2004). Several water-saving irrigation strategies have been used in recent years to improve the water productivity such as supplemental irrigation and deficit irrigation. Other scientific alternatives are also possible: integration anti-evaporation products to the soil, polymers, and use of drought-tolerant varieties. With respect to the multitude of strategies above, some researchers have turned through the basic knowledge on the physiological and biochemical mechanisms of the plant to develop a new technique "Partial Root-zone Drying" (PRD). This concept was primary used by Grimes et al. (1968) in the USA. The PRD is an irrigation technique where by half of the root zone is irrigated while the other half is allowed to dry out. The principle of PRD is that by allowing the soil on one half of a root zone to dry, those roots will send drought signals to the shoot to reduce vegetative growth and stomatal conductance leading to reduced water transpiration and hence clearly improved water use efficiency respect to conventional irrigation using higher rates of irrigation (Davies et al., 2002). The PRD irrigation has been the subject of many research works on different types of crops and fruit trees such as bean (Samadi & Sepaskhah, 1984), corn (Bahrun et al., 2002), maize (Kang & Zhang, 2004); green bean (Gencoglan et al., 2006), potato (Shahnazari et al., 2007; Shayannejad, 2009; Ahmadi et al., 2010b), tomato (Kirda et al., 2004; Zegbe et al., 2004; Wang et al., 2013), grapes (Loveys et al., 2000; Kriedman & Goodwin, 2003), Olive (Wahbi et al., 2005), peach (Gong et al., 2005), apple (Leib et al., 2006) and with different irrigation systems: drip, furrow and underground (Kang et al., 2002). Potato (*Solanum tuberosum* L.) is a water-demanding crop, requiring from 450 to 800 L to produce 1 kg of tuber dry matter (Wright & Stark, 1990). Potato is one of the strategic crops in Tunisia, where it occupies an important place in the national economy, both in terms of area as on the production side. However, this crop is constantly threatened from one region to another because of the random nature of the climate (80% of the areas are located in semi-arid and arid areas (DGEDA, 2012). This paper aims to evaluate the dry matter, yield, water consumption and water use efficiency of Potato under partial root-zone drying (PRD) in the semi-arid conditions of Tunisia.

2. Materials and Methods

2.1 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 three seasons 2009, 2010 and 2011. 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).

2.2 Estimation of Crop Potential Evapotanspiration (ETc)

The Reference evapotranspiration (ET_0) was estimated by the software CROPWAT v8.0 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:

$$ETc = Kc \times ET_0 \quad (1)$$

2.3 Plant Material and Experimental Design

Plant material consisted of one potato variety (*Solanum tuberosum* cv. Spunta). In the first experiment (2009), potato planting was conducted on March 4 with a mechanical planter machine. The Planting density was 41667 plants ha^{-1}. Concerning, the second (2010) and third experiment (2011), the same technique has been practiced. In addition, the potato planting was completed on the 01^{st} February (2010 and 2011).

Four treatments were applied: from the initiation of tuberisation to potato harvesting and they were irrigated by drip irrigation: FI treatment received 100% of ET_C (water needs by potato crop); PRD_{80}, PRD_{70}, and PRD_{60} treatments received respectively: 80, 70 and 60% of ETc at each irrigation event and it was shifted between the two sides of the plants every 2 to 10 days. All irrigation treatments (FI; PRD_{80}, PRD_{70} and PRD_{60}) realized from planting to the initiation of tuberisation stage received 100% of ETc. The experimental design was Randomize Complete Blocking Design (RCBD) with four replications. Every elementary plot had 12 m length and 6 m width (Figure 1).

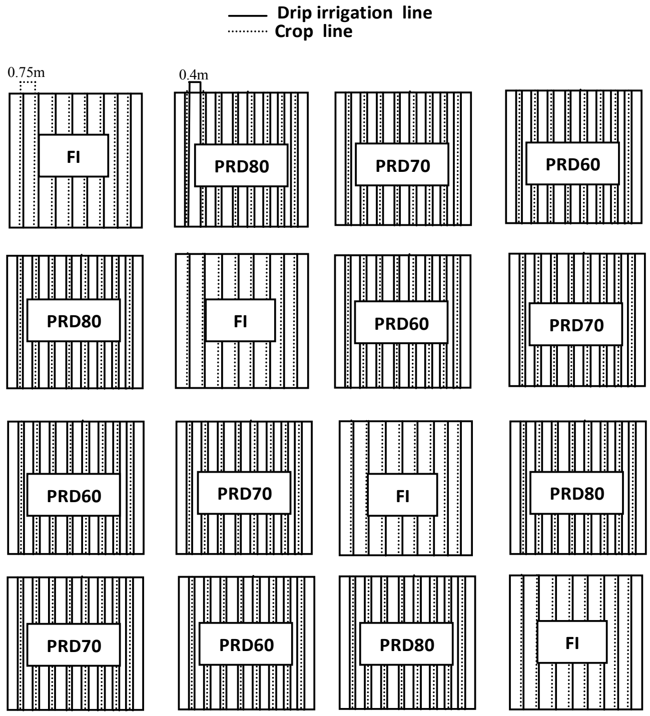

Figure 1. Experimental plot

2.4 Irrigation Treatment

The Table 1 summarizes the rainfall event and irrigation amounts during the experimental protocol for different irrigation treatments and cropping seasons of 2009, 2010 and 2011. The experimental protocol has begun at 66, 74, and 70 days after planting Potato (DAPP) respectively for 2009, 2010 and 2011. For each start date of the protocol, the irrigation treatments (FI, PRD_{80}, PRD_{70} and PRD_{60}) have the same soil moisture conditions.

The rainfall observed during the experimental protocol conducted in the campaigns 2009, 2010 and 2011, are equal to 4, 59, and 48 mm respectively. For the experimental protocol period, we recorded 8 irrigation events for the 2009 and 2011 campaigns, and 9 irrigation events for the 2010 campaign.

In fact, FI treatment, has totally received 228, 228, and 203 mm respectively for 2009, 2010, and 2011. The PRD_{80} treatment, has entirely received 184, 180, and 165mm respectively for 2009, 2010, and 2011. The PRD_{70} treatment, has completely received 158, 153, and 144 mm respectively for 2009, 2010, and 2011. The PRD_{60} treatment, has received totally 139, 134, and 120 mm respectively for 2009, 2010, and 2011.

Table 1. Rainfall (mm) and irrigation water depth (mm ha^{-1}) recorded during experimental protocol, for different irrigation treatments (FI, PRD_{80}, PRD_{70} and PRD_{60}) and cropping seasons of 2009, 2010, and 2011

				Treatments (2009)				
DAP	Rain	FI	PRD_{80}		PRD_{70}		PRD_{60}	
			Right	Left	Right	Left	Right	Left
66		26	21	0	18	0	16	0
69		32	0	26	0	22	0	19
71		26	21	0	18	0	16	0
77	4	40	0	32	0	28	0	24
81		26	21	0	18	0	16	0
86		26	0	21	0	18	0	16
94		26	21	0	18	0	16	0
98		26	0	21	0	18	0	16
Total	**4**	**228**	**184**		**158**		**139**	
				Treatments (2010)				
DAP	Rain	FI	PRD_{80}		PRD_{70}		PRD_{60}	
			Right	Left	Right	Left	Right	Left
74	3	24	19	0	16	0	14	0
77	15	24	0	19	0	16	0	14
86	8	24	19	0	16	0	14	0
90		24	0	19	0	16	0	14
94		24	19	0	16	0	14	0
97		36	0	28	0	25	0	22
99		24	19	0	16	0	14	0
101		24	0	19	0	16	0	14
106	5	24	19	0	16	0	14	0
113	28							
Total	**59**	**228**	**180**		**153**		**134**	
				Treatments (2011)				
DAP	Rain	FI	PRD_{80}		PRD_{70}		PRD_{60}	
			Right	Left	Right	Left	Right	Left
70		27	22	0	19	0	16	
78		22	0	18	0	16	0	13
85	22	27	22	0	19	0	16	
96		22	0	18	0	16	0	13
98		27	22	0	19	0	16	
104		24	0	19	0	17	0	14
117	11	27	22	0	19	0	16	
119	15	27	0	22	0	19	0	16
Total	**48**	**203**	**165**		**144**		**120**	

2.5 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. In 2009, plants were harvested for growth analysis at 35, 50, 66, and 82 days after planting Potato (DAPP). In 2010, the sampling was collected at 62, 78, 93 and 109 DAPP. In 2011, crops were collected at 63, 76, 91, and 104 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 100 DAPP for the first experiment and at 120 DAPP for the second and third experiment.

2.6 Theoretical Formulations

2.6.1 Estimation of the Daily Water Consumption

The soil moisture content in the planting zone was measured monthly with gravimetrically method. Soil water content data were collected for every 10 cm interval in soil depth. After irrigation and precipitation, additional measurements were performed. Daily water consumption of potato was calculated using the following equation (Li et al., 2010):

$$WC = P + I + U + R - D - SW \quad (2)$$

Where, Wc (mm) is the water consumption; P (mm), precipitation; I (mm), irrigation water; U the upward capillary flow into the root zone (mm) R (mm), the surface runoff, which was assumed as not significant since concrete slabs were placed around each plot; D (mm), the downward flux below the crop root zone, which was ignored since soil moisture measurements indicated that drainage at the site was negligible; and SW, the change in water storage in the soil profile exploited by crop roots (0-50 cm).

2.6.2 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:

$$WUE_{TDM}\ (Kg/m^3) = \frac{TDM}{WC} \quad (3)$$

$$WUE_Y\ (Kg/m^3) = \frac{Y}{WC} \quad (4)$$

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).

2.7 Statistical Analysis

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

3. Results

3.1 Effect of Partial Root-Zone Drying Irrigation on Crop Water Consumption

The potato daily water consumption (WC) during the three experiments (2009, 2010 and 2011) and under the four treatments (FI, PRD_{80}, PRD_{70} and PRD_{60}) was recapped in Figure 2. From these results, we observed that the potato daily water consumption (WC_{potato}) under the four treatments was irregular through the years. Nevertheless, for the three experiments (2009, 2010 and 2011) the daily progression curves of WC_{potato} under the four treatments (FI, PRD_{80}, PRD_{70} and PRD_{60}) followed the same appearance. Moreover, the daily WC of the (PRD_{60}) was lower than that of the (PRD_{70}, PRD_{80} and FI) respectively. Therefore, in the first experiment (2009), the cumulative amount of water consumption of FI was 336.5 mm next to 280.4 mm in PRD_{60}, which funds a reduction of 16.7%. Similarly, for the second experiment (2010), the daily WC by the treatment FI became more important than the PRD_{80}, PRD_{70} and PRD_{60} respectively. As a result, the cumulative amount of water consumption by FI was equal to 376 mm beside (332.4, 307.4 and 294.5 mm) in PRD_{80}, PRD_{70} and PRD_{60}, which means a reduction of (11.6, 18.2 and 21.7%) respectively. For the third experiment, the results were consistent with those above, so, the cumulative amount of water consumption by FI was equal to 341.8 mm, whereas, for the PRD_{80}, PRD_{70} and PRD_{60}, the quantity of the cumulative WC was equal to (298.5, 280.5 and 256.1 mm), which earnings a reduction of (12.6, 17.9 and 25.1%) respectively.

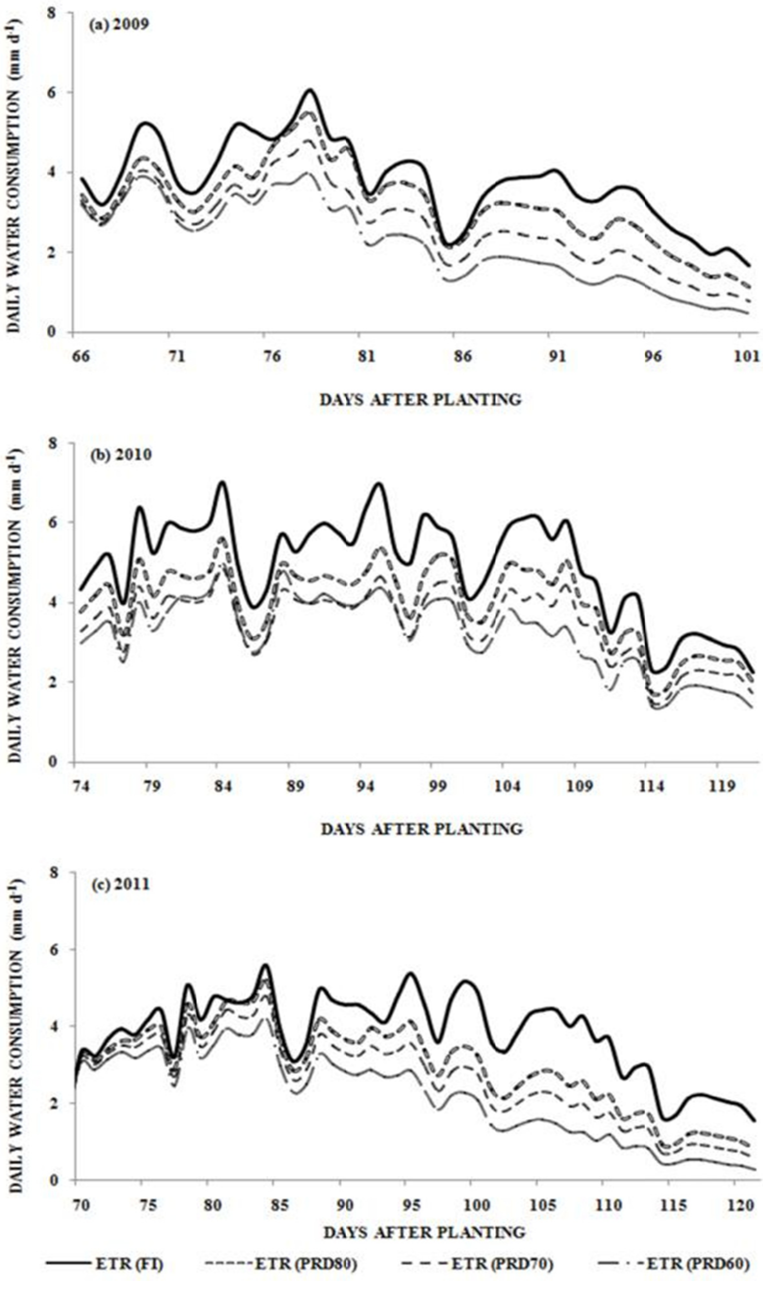

Figure 2. The daily water consumption (WC) of potato under the four treatments (FI, PRD_{80}, PRD_{70} and PRD_{60}) and during the three experiments 2009 (a), 2010 (b) and 2011(c)

3.2 Effect of Partial Root-Zone Drying Irrigation on Total Dry Matter and Yield

The impact of irrigation treatment (FI, PRD_{80}, PRD_{70} and PRD_{60}) in total dry matter production (TDM) of potato during the three experiments (2009, 2010 and 2011) was given in Figure 3.

From these results, we observed that the total dry matter production of potato at harvest (TDM_F) was more important in (FI) than that in (PRD_{80}, PRD_{70} and PRD_{60}) treatments. In fact, the maximum value of TDM_F was marked in the treatment FI and has varied from 855.7 to 976.4 g m^{-2}. After that, the treatment PRD_{60} and it registered a fluctuation in TDM between 776.5 and 905.7 g m^{-2}. Nevertheless, the lowest value of TDM_F was various according the years between the two treatments (PRD_{80} and PRD_{70}). Consequently, the TDM_F in FI has recorded respectively an increased of (16.3, 24.2 and 17.5%); (26, 14.9 and 16.4%) and (5.2, 7.2 and 12.1%) compared to PRD_{80}, PRD_{70} and PRD_{60}. In the first experiment (2009), variance analysis showed that there was no significant effect (P > 0.05) between the two treatments (FI and PRD_{60}) on TDM_F. However, ANOVA analysis showed that there was significant effect (P < 0.05) between FI and (PRD_{80} and PRD_{70}). During the second and third experiment (2010 and 2011), variance analysis showed that there was significant effect (P < 0.05) of treatment on TDM_F between the four treatments (FI, PRD_{80}, PRD_{70} and PRD_{60}).

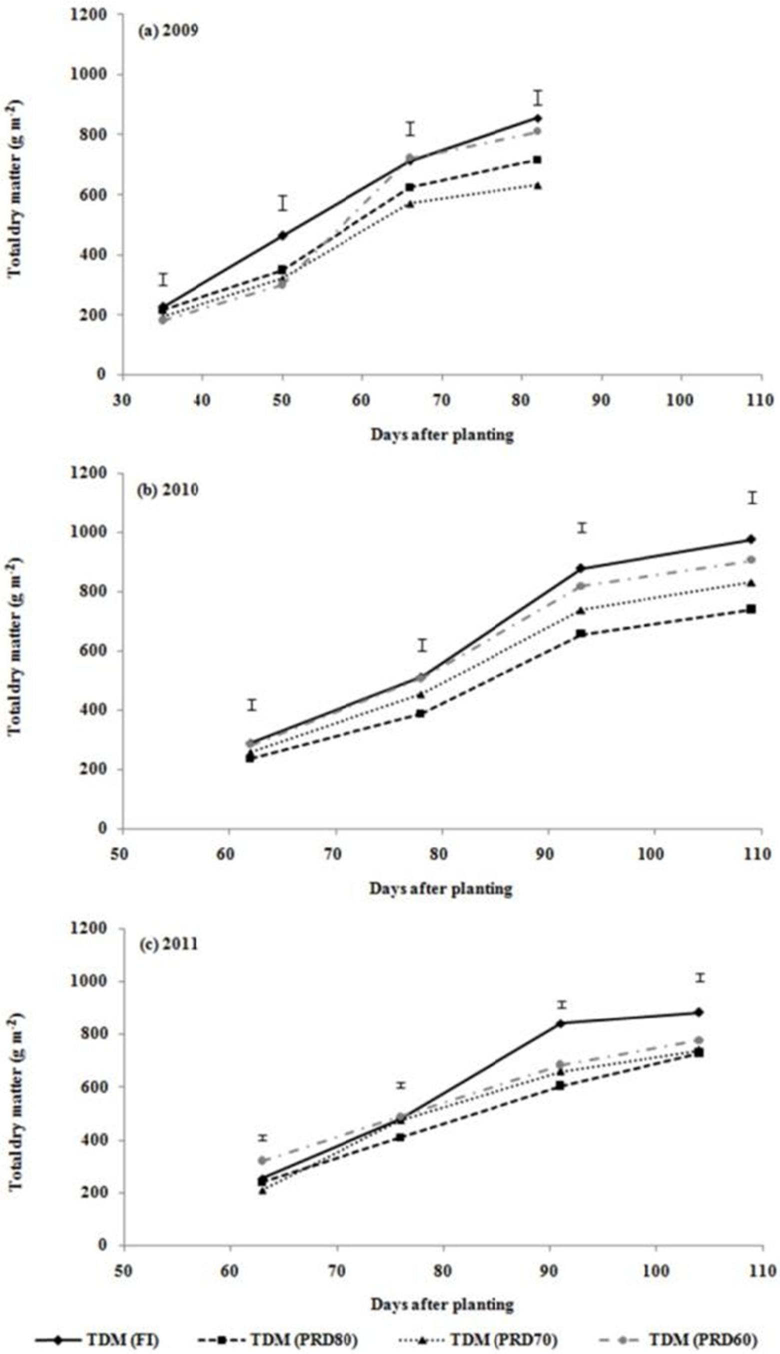

Figure 3. The Total dry matter production (TDM) of potato under the four treatments (FI, PRD_{80}, PRD_{70} and PRD_{60}) and during the three experiments 2009 (a), 2010 (b) and 2011(c)

The effect of Partial Root-Zone Drying Irrigation treatment (FI, PRD_{80}, PRD_{70} and PRD_{60}) in the potato yield during the three experiments (2009, 2010 and 2011) was revealed in Table 2.

In this circumstance, we noted that the potato yield at harvest (Y_F) was more important in FI than that in treatments PRD_{80}, PRD_{70} and PRD_{60}. In detail, for the three experiments (2009, 2010 and 2011), the maximum value of Y_F was marked in the treatment FI and it was respectively equal to (25.6, 42.9 and 39.1t ha^{-1}). After that, the treatment PRD_{60} has registered the second rank in the first experiment (25.2 t ha^{-1}). However, the treatment PRD_{70} has occupied the same position in the second and third experiments and it was respectively equivalent to (41.2 and 36.2 t ha^{-1}). Thus, during the three experiments (2009, 2010 and 2011), the Y_F in FI has recorded respectively an increased of (16.4, 26.1 and 22%); (18.3, 4 and 7.4%) and (1.6, 11.9 and 16.9%) compared to PRD_{80}, PRD_{70} and PRD_{60}.

For the three experiments (2009, 2010 and 2011), variance analysis showed that there was no significant effect ($P > 0.05$) between the three treatments (FI, PRD_{70} and PRD_{60}) on Y_F. However, in the second and third experiment (2010 and 2011), ANOVAs analysis showed that there was significant effect ($P < 0.05$) between FI and PRD_{80}.

Table 2. The yield of potato under the four treatments (FI, PRD_{80}, PRD_{70} and PRD_{60}) and during the three experiments 2009, 2010 and 2011

Treatments	**Yield (T ha^{-1})**		
	2009	**2010**	**2011**
FI	25.6 a	42.9 a	39.1 a
PRD_{80}	21.4 a	31.7 b	30.5 b
PRD_{70}	20.9 a	41.2 a	36.2 ab
PRD_{60}	25.2 a	37.8 a	32.5 ab
LSD (5%)	7.4	6.2	7.4

3.3 Effect of PRD Irrigation Treatments on Water Use Efficiency

The conversion efficiency of water consumption into potato yield (WUE_Y) under the four treatments (FI, PRD_{80}, PRD_{70} and PRD_{60}) and during the three experiments is presented in table 3.

In the first experiment (2009), we observed that the WUE_Y was more important in PRD_{60} than that in treatments FI; PRD_{80} and PRD_{70}. In fact, the WUE_Y of the treatment PRD_{60} has recorded respectively an increased of (15.6, 24.4 and 22.2%); compared to FI, PRD_{80} and PRD_{70}. Nevertheless, variance analysis showed that there was no significant effect ($P > 0.05$) between the four treatments (FI, PRD_{80}, PRD_{70} and PRD_{60}) on WUE_F.

In the second and third experiment (2010 and 2011), the WUE_Y of the treatment PRD_{60} has apparent respectively an increased of (10.9 and 10.2%) and (25.8 and 19.7%) compared to FI and PRD_{80}. Thus, ANOVAs analysis showed that there was significant effect ($P < 0.05$) between PRD_{60} and (FI and PRD_{80}) on WUE_Y.

Table 3. The water use efficiency of potato yield under the four treatments (FI, PRD_{80}, PRD_{70} and PRD_{60}) and during the three experiments 2009, 2010 and 2011

Treatments	**WUE_{RDT} (kg m^{-3})**		
	2009	**2010**	**2011**
FI	7.6 a	11.4 b	11.4 ab
PRD_{80}	6.8a	9.5 c	10.2 b
PRD_{70}	7.0 a	13.4 a	12.9 a
PRD_{60}	9.0 a	12.8 ab	12.7 a
LSD (5%)	2.3	1.9	2.4

The relation connecting the water consumption and the total dry matter production over all potato growing season during the three experiments and under the four treatments is given in Figure 4.

From these results, we observed clearly under the four treatments (FI, PRD_{80}, PRD_{70} and PRD_{60}) 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_{MST}). Similarly, we noted that under the three potatoes cropping seasons (2009, 2010 and 2011), the highest amount of WUE_{MST} has registered under the treatment PRD_{60} and it was equal to (4.11; 3.87 and 3.97 kg m^{-3}) respectively. However, the lowest was achieved by the treatment PRD_{70} during the first experiment (2.69 kg m^{-3}) and by PRD_{80} under the second and third experiment (2.67 and 3.38 kg m^{-3}).In this regard, during the three cropping seasons (2009; 2010 and 2011), the treatment PRD_{60} has recorded respectively an increase of (19.4; 21.5 and 1.8%); (29.1; 30.9 and 14.8%) and (34.4; 12.5 and 1.3%) compared to FI, PRD_{80} and PRD_{70}.

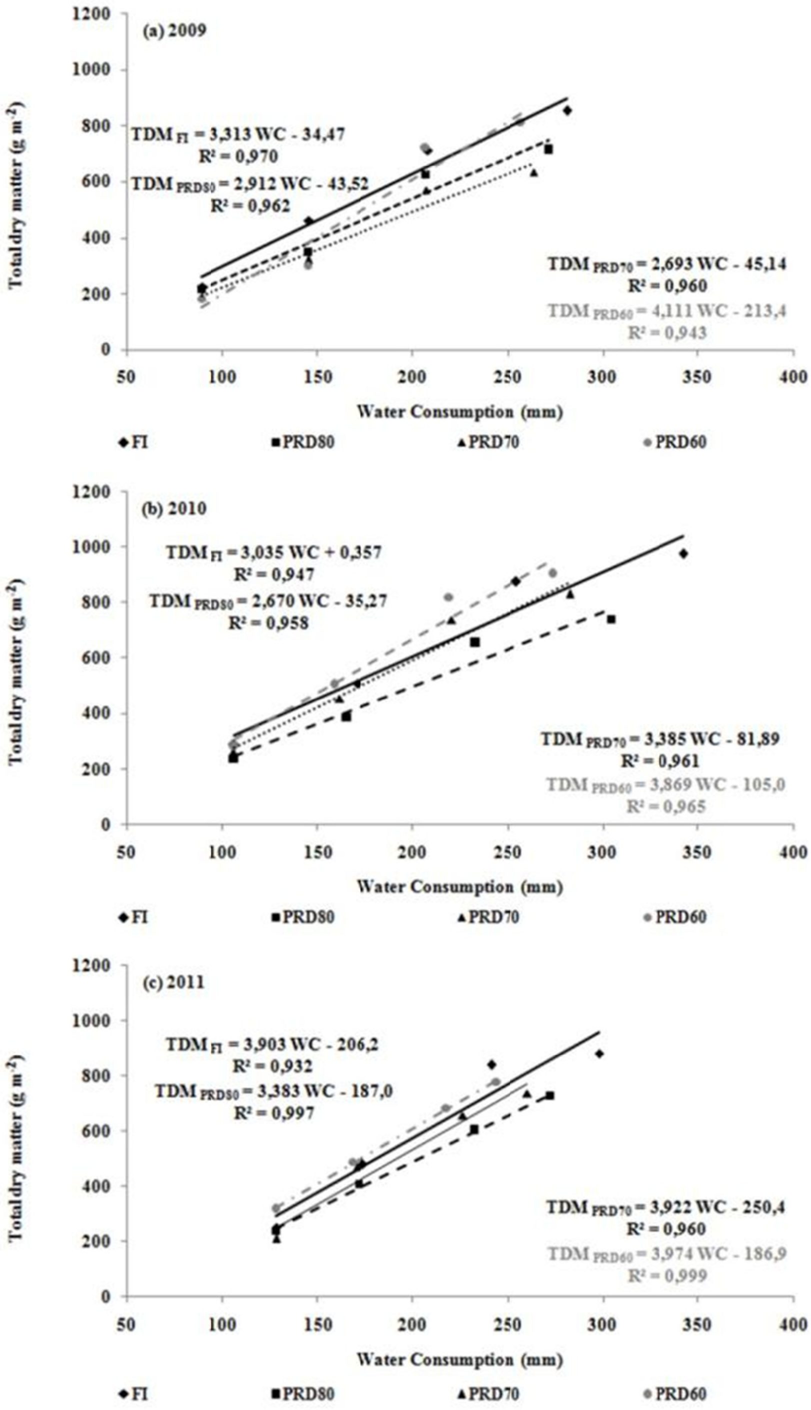

Figure 4. The conversion efficiency of water consumption into total dry matter production over all potato growing season (WUE_{TDM}) under the four treatments (FI, PRD_{80}, PRD_{70} and PRD_{60}) and during the three experiments 2009 (a), 2010 (b) and 2011(c)

4. Discussion

The effect of the Partial Root-Zone Drying Irrigation technique (FI, PRD_{80}, PRD_{70} and PRD_{60}) on the water consumption (WC), the total dry matter production (TDM), the potato yield (Y), the conversion efficiency of water consumption into total dry matter production (WUE_{TDM}) and the conversion efficiency of water consumption into potato yield (WUE_{Y}) were scrutinized.

The results have shown (Figure 2), that for the three potatoes growing season (2009, 2010 and 2011), the maximum amount of cumulative WC was obvious in the treatment FI and the lowest value was observed in the treatment PRD_{60}. As a result, the cumulative amount of WC in PRD_{60} has recorded respectively a decreased of (16.7; 21.7 and 25.1%) compared to FI. These reductions in water consumption achieved at the PRD_{60}, have helped to save respectively 89, 94, and 83 mm of irrigation water. These results of water saving were in agreement with those obtained by Shahnazari et al. (2007). The latter authors observed that in the FI and PRD treatments, even when the irrigation water application was reduced by 30% during extended periods of PRD treatment, which saved 61 mm of water. Similarly, Liu et al. (2006b) avowed that the evapotranspiration (ET) in deficit irrigation and PRD treatment was significantly less than that in the treatment full irrigation (FI). In the same way, Saeed et al. (2008) and Xie et al. (2012) affirmed that the two PRD treatments (PRD_{70} and PRD_{50}) utilized respectively 29 and 50% less water than the treatment full irrigation (FI). Besides, we observed that the PRD treatment affect the TDM accumulation (Figure 3). However, the two treatments PRD_{80} and PRD_{70} were more overstated by the impact of Partial Root-Zone Drying Irrigation technique on TDM reduction than PRD_{60}. In the same way, for the three potatoes cropping seasons (2009, 2010 and 2011), variance analysis showed that there was no significant effect ($P > 0.05$) of the Partial Root-Zone Drying Irrigation technique on potato yield between the two treatments (FI and PRD_{60}). In opposition, ANOVAs analysis showed that there was significant effect ($P < 0.05$) between FI and PRD_{80}. These findings are in line with those of Loveys et al. (1998), Dry et al. (2000), Bacon (2003), and Gu et al. (2004). They observed that PRD has been profitably used in numerous plants like tomatoes, grapes, oranges, olive trees and maize in which it reduced the water consumption by more than 50% without negative effects on yields. Also, Liu et al. (2006b) and Ahmadi et al. (2010b) showed that PRD have not significant effects in potato tuber yield between full irrigation and PRD (70% and 50% of water applied to full irrigation from tuber initiation to maturity). Saeed et al. (2008) and Xu et al. (2011) registered the highest tuber yield in the PRD treatments as soon as water restriction was initiated after tuber initiation. As well, Xie et al. (2012) found that the PRD_{50} produced similar ($P > 0.05$) yields to the two conventional irrigation (C_{100}: full irrigation and C_{50}: deficit irrigation = 50% of FI) and under two sites respectively in Hohhot and Lanzhou.

As given away by the outcome in (Figure 4 and Table 3), the conversion efficiency of water consumption into dry matter production (WUE_{TDM}) and the conversion efficiency of water consumption into potato yield (WUE_{y}) were increased by the Partial Root-Zone Drying Irrigation in a remarkable way in the (PRD_{60}). The highest amounts of (WUE_{TDM}) were obtained respectively during the three potatoes growing seasons (2009, 2010 and 2011) under the PRD_{60} (4.11 kg m^{-3}, 3.87 kg m^{-3} and 3.97 kg m^{-3}). Equally, the uppermost (WUE_{Y}) was achieved in PRD_{60} during the first experiment and in PRD_{70} through the second and third experiment. However, for the three experiments, variance analysis showed that there was no significant effect ($P > 0.05$) of the Partial Root-Zone Drying Irrigation technique on WUE_{Y} between the two treatments (FI and PRD_{60}). In detail, the cumulative water consumption marked respectively during the three experiments (2009, 2010 and 2011) under the FI treatment (336.5, 376 and 341.8 mm) has decreased to (280.4, 294.5 and 256.1 mm) under PRD_{60}. Even so, ANOVAs analysis showed that there was no significant effect ($P > 0.05$) of the Partial Root-Zone Drying Irrigation technique on TDM and Y between the two treatments (FI and PRD_{60}). In fact, the enhancement of the conversion efficiency of water consumption into potato yield in Partial Root-Zone Drying Irrigation PRD_{60} can be explained by the fact that water consumption has decreased and the tuber yield is sustained. However, the improvement of the conversion efficiency of water consumption into total dry mater production in Partial Root-Zone Drying Irrigation PRD_{60} can be explained by the fact that water consumption has decreased by more than total dry matter production decrease. Likewise, these results are consistent with those of various researches (Liu et al., 2006a; Saeed et al., 2008; Shahnazari et al., 2007; Jovanovic et al., 2010; Xie et al., 2012). They found that the earliest PRD_{50} treatment decreased water consumption, sustained tuber yield and improved WUE. In this framework, Saeed et al. (2008) found that the Partial Root-Zone Drying Irrigation utilized 29% less water and improved the water use efficiency by 19%. Similarly, Xie et al. (2012) affirmed that the PRD_{50} treatment utilized 50% less water and increased WUE by 48%. Yactayo et al. (2013) recommend that the earliest PRD application (ca tuber initiation onset) in arrangement with the middle water restriction levels improve WUE and sustain yield. Liu et al. (2006b) studied the effects of full irrigation (FI) and Partial Root-Zone Drying Irrigation (PRD_{50} = 50% of FI) on water use efficiency (WUE). They found that PRD_{50} used 37% less water than FI, while water use efficiency was similar to FI. In potato, xylem-ABA production has been suggested as a major driver of enhanced WUE under induced water restriction (Liu et al., 2006a). It has been suggested that ABA limits ethylene production with a concomitant effect of senescence retardation in leaves, flowers and fruits (Morgan & Drew, 1997; Sharp, 2002).

5. Conclusions

Under the conditions of this work, we were able to deduce, that the Partial Root-Zone Drying Irrigation Technique (PRD) is a potential water-saving irrigation strategy, especially for the drought sensitive crop such as potatoes and with limited water conditions. In fact, it can be conclude that, the use of PRD with 60% of ETc from the initiation of tuberisation stage to harvest, has a advantages compared to full irrigation in terms of improving the water use efficiency, while keeping the same tuber yield as that of the FI treatment.

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