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Effect of Partial Root Zone Drying and Deficit Irrigation Techniques for Saving Water and Improving Productivity of Potato

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Abstract : Water shortage is the most important factor constraining agricultural production all over the world. New irrigation strategies must be established to use the limited water resource more efficiently. Partial root drying (PRD) is a new irrigation and plants growing technique which improves water use efficiency without significant yield reduction. Two field experiments were carried out during growing seasons 2014 and 2015, it executed in private farm in Baiyala City, Kafer El-Sheikh Governorate , Egypt to study the effect of partial rootzone drying (PRD) and deficit irrigation (DI) techniques for saving water and improving productivity of potato crop. The study factor was PRD technique compared with furrow irrigation "FI" under DI (100% ETc, 75% ETc and 50%ETc). The following parameters were studied to evaluate the effect of PRD technique: 1) Growth of potato, 2) Yield of potato, 3) water productivity of potato "WP_{potato}" and 4) Quality traits like carbohydrates and protein content. Results of statistical analysis for effect of PRD technique on yield, quality traits and WP_{potato} indicated that, there were no significant differences between FI+100%ETc and PRD where, FI+100%Etc>PRD> FI+75%ETc >FI+50%ETc This irrigation technique "PRD" is promising for application in arid regions for saving water up to 50% from crop water requirements.
Keywords: partial root zone drying; deficit irrigation; water productivity; potato; furrow irrigation; water scarcity.

Introduction

Drought is a severe environmental stress limiting agricultural production in many countries. However, in Egypt water availability for agriculture production is being reduced as a consequence of global climate change, and growing demand for other uses. Also, water scarcity in Egypt is expected to be more severe especially after the commencement of constructing the Grand Ethiopian Renaissance Dam. Therefore, great emphasis is placed on water management for dry conditions based on plant physiology, with the aim of increasing water use efficiency. Maximizing irrigation water use efficiency is a common concept used by irrigation project managers; also, the visual quality of the crop yield is the primary criteria on used to assess irrigation systems effectiveness. In recent years, however, growing competition for scarce water resources has led to applying modified techniques for maximizing water use efficiency and improving crop yields and quality, particularly in arid and semi arid regions as like Egypt [1].

Potato (*Solanum tuberosum* L.) is the world's fourth-largest food crop, following rice, wheat and maize. In Egypt, Potato is the second most important vegetable crop after tomato. Egypt also ranks among the world's top potato exporters. The potato cropping area has been expanding in new cropping areas in some environments that could be negatively affected by global warming[2]. A reduction of 18–32% of potato global yield caused by drought caused by climate change is projected to occur during 2010–2039[3]. Potato is a crop that is very sensitive to water stress, which makes it a water-demanding crop, which require from 400 to 600 liters of water to produce 1 kilogram of tuber dry matter [4]. Potato's limited tolerance to drought is due to its relatively shallow root system and the stomatal tendency to close[5], which reduce leaf extension rates. Stomatal closure also reduces CO_2 uptake and photosynthetic activity, increases leaf temperature and photorespiration, and consequently had a negative effect on crop production[6]. Therefore, irrigation is always needed for the production of high-yielding crops[7]. However, the increasing global shortage of water resources requires the optimization of irrigation management in order to improve water use efficiency (WUE). Controlling of stomatal opening in potato in order to increase the yield per unit volume of transpired water has been suggested [8].

Partial root-zone drying (PRD) is an irrigation method that attempts to manipulate plant response to root drying in order to decrease the water demand. PRD is an irrigation technique whereby half of the root zone is irrigated while the other half is allowed to dry out. Water supply is then cyclically reversed allowing the previously well-watered side of the root system to dry down while fully irrigating the previously dried side. PRD is called also alternative irrigation method with furrow irrigation system and where [9] reported that produced PRD produced the highest values of irrigation water use efficiency. When PRD irrigation is applied to a crop, the normal root to shoot signaling system that operates in water-deficient soils is altered, causing the drying half of the root system to release ABA thus reducing stomatal opening, whereas the fully hydrated roots preserve a favorable water status throughout the shoot parts of the plant. PRD is based in the theoretical hypothesis that this mixed root signals causes a limited closure of stomata to limit water vapor with a minimum effect on CO_2 uptake and photosynthesis[10]. It is expected that contrary root signals caused by PRD would make a slight reduction of the stomatal opening that would decrease the water loss substantially with only a small effect on the photosynthesis rate, provided plant turgor is maintained by the watered fraction of the root system. The opinion behind 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 use. The expected outcome is reasonably good yields with considerable water savings and higher water use efficiency (WUE), which is very importance in areas like Egypt where water resources are limiting. PRD also stimulates the growth of secondary roots, which reduces the susceptibility to drought[11]. A root system widely distributed in the soil volume as a result of the lateral dry-wet cycle can cause an improved uptake of nutrients and water by the root system [12]. PRD has been successfully used in several crops such as tomatoes, corn, cotton and others, PRD has been shown to be successful in grapevines and in other vegetables[13,14,15], but no extensive research has been conducted in tuber crops, particularly in semi-arid environments like Egypt where the water resource is very limited. The results in the former crops demonstrated that PRD has no major negative effect on the yield but improves fruit quality with a reduction of more than 50% of the consumption of water [16]. However, important issues such as the growth stage at which PRD should be applied to the potato crop to improve WUE without yield reductions need to be addressed.

Therefore, the objectives of this study were, to investigate the suitability of deficit irrigation strategies by deficit irrigation (DI) and partial root drying (PRD) for clay soils, to study the impact of DI and PRD on yield, quality and water productivity of potato grown under arid Egyptian conditions.

Material and Methods

2.1. Experimental Site:

Two field experiments were carried out during growing seasons 2014 and 2015, it executed in private farm in Baiyala City, Kafer El-Sheikh Governorate , Egypt. The experimental area has an arid climate with cool winters and hot dry summers prevailing in the experimental area. The data of maximum and minimum temperature, relative humidity and wind speed were obtained from the Central Laboratory of Meteorology which is related to Ministry of Agriculture, Egypt. There was not rainfall that could be taken into consideration through the two seasons, because the amount was very little and the duration didn't exceed few minutes.

2.2. Some physical and chemical properties of soil and irrigation water:

The water has a pH of 7.32 and an average electrical conductivity of 0.43 dS m^{-1}.The main physical and chemical properties of the soil were determined on site and in the laboratory at the beginning of the trial and are reported in tables (1, 2).

Table (1) Mechanical and physical soil properties of experimental site at different depths.

Soil depth, cm	Physical soil properties			Mechanical soil properties				
	Bulk density, g/cm^3	Field capacity, %	Wilting point, %	Sand, %	Fine sand, %	Silt, %	Clay, %	Soil texture
0 – 20	1.22	47.4	27.3	1.7	15.4	18.7	64.2	Clay
20 - 40	1.25	45.3	28.5	1.9	15.9	17.7	64.5	Clay
40 - 60	1.35	44.7	32.8	1.8	14.2	18.2	65.8	Clay

Table (2) Chemical soil properties of experimental site at different depths.

Soil depth, cm	pH	EC mmhos/ cm	Cations				Anions			
			Ca^{++}	Mg^{++}	K^{+}	Na^{+}	Cl^{-}	Co_3^{--}	Hco_3^{-}	So_4^{--}
0 – 20	8.2	2.5	5.66	5.11	0.34	9.1	10.6	-	3.5	6.11
20 - 40	8.1	2.4	4.77	4.21	0.38	12.3	14	-	6.2	1.46
40 - 60	8.5	2.8	5.14	6.39	0.35	15.0	14.1	-	5.33	7.45

2.3. Experimental Design:

The study factor was PRD technique compared with furrow irrigation "FI" under DI (100% ETc, 75% ETc and 50%ETc). The total numbers of plots were 12 with 2880 m^2area each. This plots divided into three replicates and each replicate consist of 4 plots. The area of each plot was 240 $m^{2.}$ The statistical design of this experiment was random block design. Profile probe was placed in each plot to detect the soil moisture.

2.4. Irrigation requirements of potato:

The irrigation requirements were based on the reference evapotranspiration equation of Penman-Monteith using daily data of the in site weather station. Total water volumes for each treatment are reported in table (3).

Table (3) Total water volumes for each treatment

Irrigation treatments	Irrigation no.	Irrigation intervals	Irrigation volumes, m^3 fed^{-1}	
	N	N	2014	2015
100% ETc	9	12	1800	1894
75% ETc	9	12	1350	1420
50% ETc	9	12	900	947
PRD (50% ETc)	9	12	900	947

ETc: Evapotranpiration for potato crop

2.5. Evaluation parameters:

Leaf area index, chlorophyll content, total dry matter and harvest index were obtained at regular intervals. At harvest, a random sample was taken from each plot to determine yield, this was then converted into yield in t $fedden^{-1}$ and Also, water productivity, carbohydrates and protein content were determined.

Water productivity of $_{potato}$"WP_{potato}" was calculated according to James equation (1), (1988) as follows:

WP_{potato} = (Ey/Ir) x100

Where: WP_{potato} is the water productivity of maize (kg potato m^{-3}water), Ey is the economical yield (kg fed^{-1}); Ir is the amount of applied irrigation water (m^3water $fed^{-1}season^{-1}$).

2.6. Statistical analysis:

Data of the two seasons were statistically analyzed according the procedures of Snedecor and Cochran and Waller and Duncan.

Results and Discussion

1. Growth of potato

Figs.(1, 2) and data in table (1) showed the effect of partial rootzone drying (PRD) and deficit irrigation (DI) techniques on leaf area index and total chlorophyll **.** There were significant differences between values of leaf area index during two seasons 2014 and 2015. The highest values for leaf area index were under 100%ETc and PRD treatments and statistical analysis indicated that no significant between 100% ETc treatment and PRD treatment. This mainly due to that contrary root signals caused by PRD would make a slight reduction of the stomatal opening that would decrease the water loss substantially with only a small effect on the photosynthesis rate, provided plant turgor is maintained by the watered fraction of the root system. The opinion behind 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 use. When PRD irrigation is applied to a crop, the normal root to shoot signaling system that operates in water-deficient soils is altered, causing the drying half of the root system to release ABA thus reducing stomatal opening, whereas the fully hydrated roots preserve a favorable water status throughout the shoot parts of the plant. PRD is based in the theoretical hypothesis that this mixed root signals causes a limited closure of stomata to limit water vapor with a minimum effect on CO_2 uptake and photosynthesis[10].

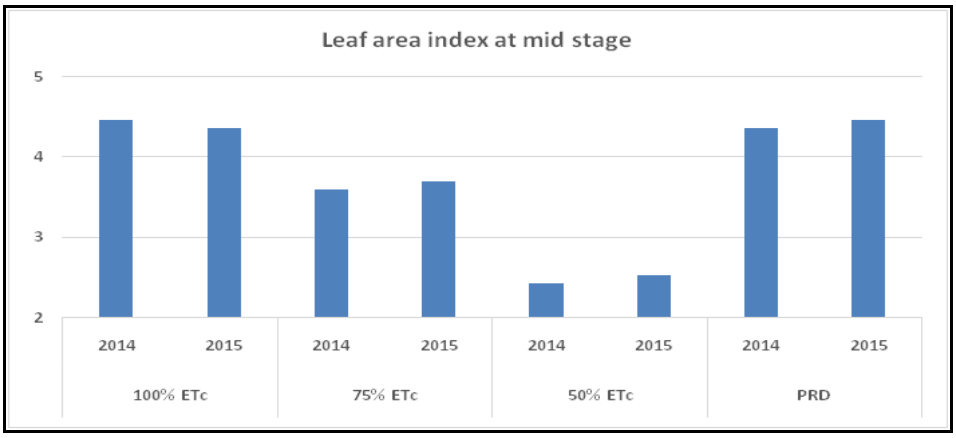

Fig. (1) Effect of partial rootzone drying (PRD) and deficit irrigation (DI) techniques on leaf area index at mid stage

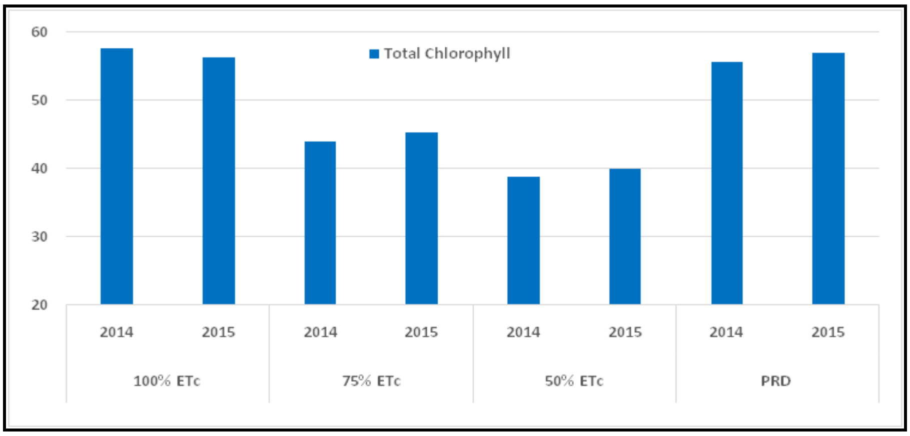

Fig. (2) Effect of partial rootzone drying (PRD) and deficit irrigation (DI) techniques on total chlorophyll

2. Yield of potato

Figs.(3 ,4, 5) and data in table (1) showed the effect of partial rootzone drying (PRD) and deficit irrigation (DI) techniques on total dry matter, harvest index and yield of potato**.** There were significant differences between values of total dry matter, harvest index and yield of potato during two seasons 2014 and 2015. The highest values for total dry matter, harvest index and yield of potato were under 100% ETc and PRD treatments and statistical analysis indicated that no significant between 100% ETc treatment and PRD treatment. This mainly due to the expected outcome is reasonably good yields with considerable water savings and higher water use efficiency (WUE), which is very importance in areas like Egypt where water resources are limiting.

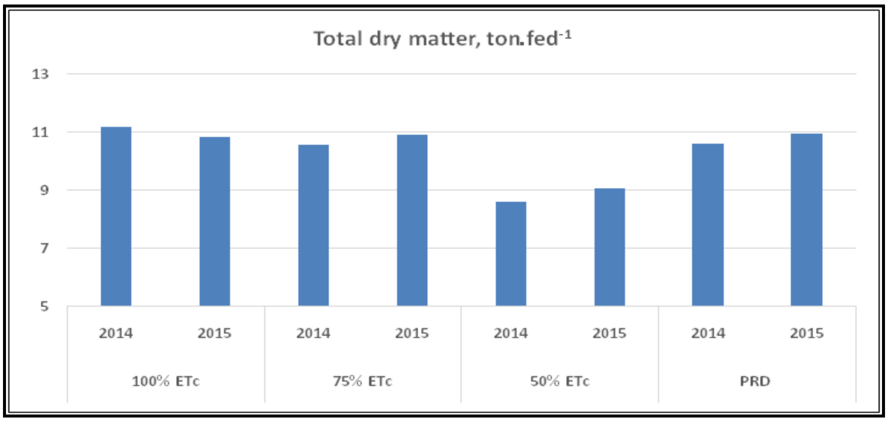

Fig.(3) Effect of partial rootzone drying (PRD) and deficit irrigation (DI) techniques on total dry matter

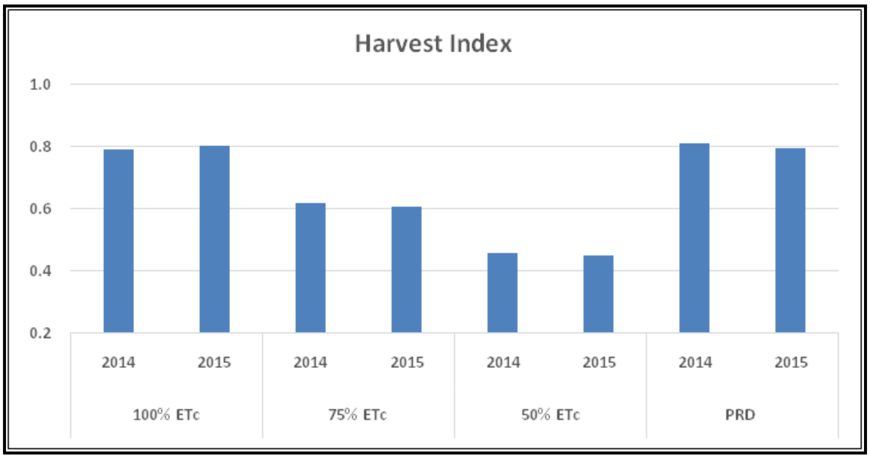

Fig.(4) Effect of partial root zone drying (PRD) and deficit irrigation (DI) techniques on harvest index

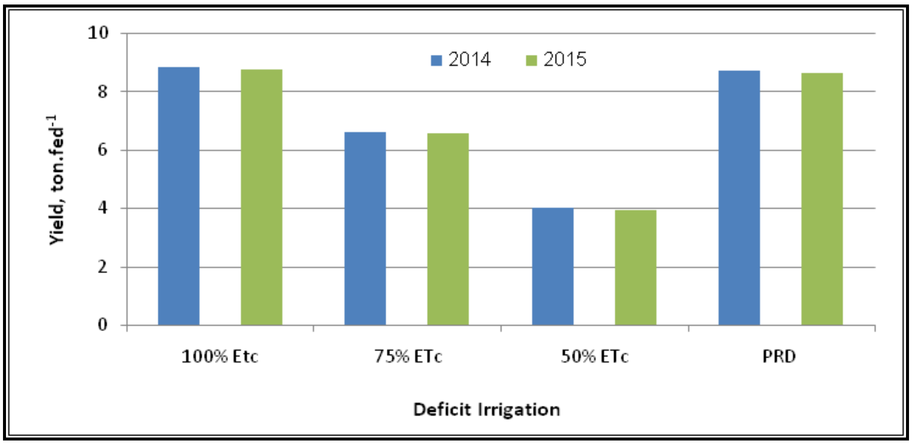

Fig.(5) Effect of partial root zone drying (PRD) and deficit irrigation (DI) techniques on yield of potato

3. Water productivity of potato

The water productivity of potato was calculated as amount of crop yield produced in kg per cubic meter of irrigation water. Total water volume irrigation was 1800 $m^3$for 2014 and 1894 $m^3$for 2015. Figs.(6) and data in table (1) showed the effect of partial root zone drying (PRD) and deficit irrigation (DI) techniques on water productivity of potato**.** There were significant differences between values of water productivity of potato during two seasons 2014 and 2015. The highest values of WP_{potato} were 9.17 and 8.65 kg m^{-3} under PDR for 2014 and 2015 respectively and there were high significant differences between values of WP under PRD and other treatments.

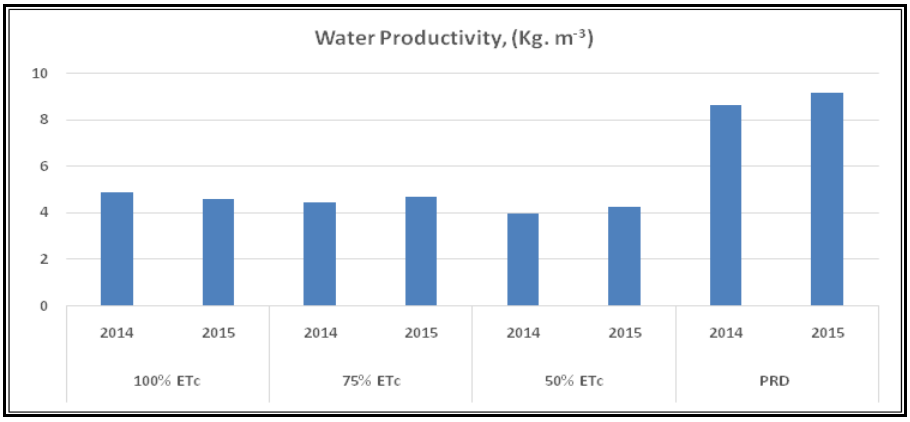

Fig.(6) Effect of partial root zone drying (PRD) and deficit irrigation (DI) techniques on water productivity of potato

4. Quality traits

Figs.(7) and data in table (1) showed the effect of partial root zone drying (PRD) and deficit irrigation (DI) techniques on carbohydrates and protein content of potato**.** There were significant differences between values of carbohydrates and protein content of potato during two seasons 2014 and 2015. The highest values for carbohydrates and protein content of potato were under 100%ETc and PRD treatments and statistical analysis indicated that no significant between 100% ETc treatment and PRD treatment. This also due to the same effect of PRD technique.

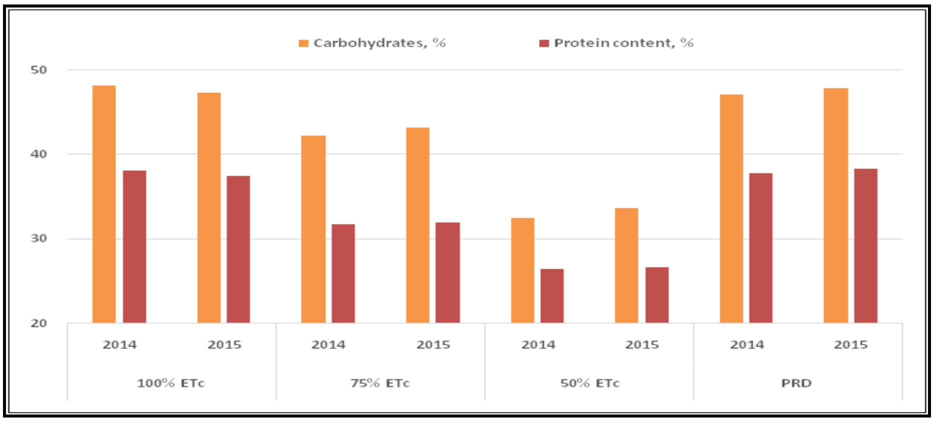

Fig.(7) Effect of partial root zone drying (PRD) and deficit irrigation (DI) techniques on carbohydrates and protein content of potato

Table (4) Effect of partial root zone drying (PRD) and deficit irrigation (DI) techniques on leaf area index at mid stage, total chlorophyll, total dry matter, harvest index, yield, water productivity, carbohydrates and protein content of potato

	Deficit Irrigation	**Leaf Area Index at Mid Stage**	**Total Chlorophyll**	**Total Dry Matter ton fed^{-1}**	**Harvest Index**	**Yield, ton.fed^{-1}**	**Water Productivity, kgm^{-3}**	**Carbohydrates,%**	**Protein content, %**
2014	100% Etc	4.46 a	57.63	11.17 a	7.8 a	8.82 a	4.90 b	48.13	38.13
	75% ETc	3.70 a	45.23	10.91 a	6.0 b	6.62 b	4.73 b	43.20	32.00
	50% ETc	2.53 b	40.03	9.06 b	4.4 c	4.04 c	4.25 b	33.60	26.67
	PRD	4.46 a	56.97	10.95 a	7.9 a	8.71 a	9.17 a	47.87	38.33
LSD 5%		**0.83**	**4.29**	**0.86**	**0.5**	**0.88**	**0.86**	**3.61**	**3.28**
2015	100% Etc	4.36 a	56.33	10.82 a	8.0 a	8.75 a	4.62 b	47.33	37.50
	75% ETc	3.60 a	43.93	10.54 a	6.2 b	6.56 b	4.46 b	42.23	31.73
	50% ETc	2.43 b	38.73	8.61 b	4.5 c	3.95 c	3.96 b	32.43	26.43
	PRD	4.36 a	55.67	10.60 a	8.1 a	8.63 a	8.65 a	47.17	37.77
LSD 5%		**0.83**	**4.29**	**0.93**	**0.5**	**0.91**	**0.85**	**3.03**	**3.54**

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