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Evaluating the Effects of Deficit Irrigation Strategies on Potato (*Solanumtuberosum* L.) Yield, Tuber Quality and Water use Efficiency

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ABSTRACT

Adopting efficient irrigation strategies is necessary because of climate change and growing population especially in regions that receive low precipitation. A field experiment was performed at three replications for two years (2013 and 2014) as split-split-plot in Chaharmahal-Va-Bakhtiari Province, Shahrekord.The main plotswereirrigation type (furrow and tape drip irrigation), sub-plots including potato cultivars (Almeraand Burren) and secondary sub-plots were deficit irrigation (DI) managements (FI=100%, RDI_{80}= 80%, RDI_{65}= 65% of available water depletion and partial-root-zone-drying (PRD) during growth period).Influences of these treatments have been studied on tuber yield, dry matter, starch and proline content, water use efficiency (WUE) and water productivity (WP).Results declared that DI management had significant effects at P $\leq$0.01on entire studied parameters. The highest and lowest tubers yield 52.8 and 25.5 $tonha^{-1}$ were related to FI and RDI_{65} treatments, respectively. Tubers yield reduced noticeably by 8% in plants receiving 80% IR and PRD irrigation and by 52% in plants receiving RDI_{65} irrigation. The means comparison revealed a relationship between PRD and RDI_{65} for the highest and lowest values of WUE with 14.5 and 8.46 kgm^{-3}, respectively.Additionally, outcomes demonstrated that tape drip irrigation enhanced CPD by 79% compared to furrow irrigation. Means comparison showed that the highest values of CPD with 10.77 kgm^{-3} was related to Burren cultivar and this cultivar increased CPD by 21% compared to Almera cultivar. Therefore, it is essential to select irrigation method under environmental parameters of plant in order to enhance production per unit of water consumed. These findings highlight the importance of adopting efficient irrigation strategies to optimize water consumption and increase tuber yield in regions facing water scarcity and climate challenges.

Keywords: Irrigation type, Water management, Partial-root-zone-drying, Water productivity, Arid region.

INTRODUCTION

“Water crisis is a severe global concern which led to reduction of crop productionin many countries around the world” (Asmamaw *et al*., 2021; Saad *et al*., 2023).The world's water consumption has increased six times in the last 100 years and is still rising about 1% annually (UNESCO, 2020). Consequently, a growing portion of the populace will confront water shortages (Gleick, 2003; Hanjra and Qureshi, 2010).

Globally, between 70 and 86 percent of all water resources used for agriculture and is the main cause of the increasing level of regional water scarcity (Hoekstra *et al*., 2012; Jaramillo and Destouni, 2015; Rosa *et al*., 2020). “Potato (*Solanum tuberosum* L.) with 368 Mt and an area of 20 Mha, is the fourth most widely crop in the world” (Martinez-Romero *et al*., 2019). Because of its vital role in food security (Sanchez *et al*., 2020) and is a water-stress-sensitive crop (Ati *et al*., 2012). With an annual production of 4474886 tons from 131073 ha, Iran is the world's 19th-largest producer of potatoes.

In many arid regions worldwide, implementing effective water management is crucial for enhancing water use efficiency (WUE) during conditions of water shortage in order to preserve crop production (Malek *et al*., 2018; Chakravarti *et al*., 2022).Less water is applied than what is needed by the crop in deficit irrigation (DI). While the consequences on yield are less severe in this instance, water usage is also significantly decreased (Valcárcel *et al*., 2020). This method has been widely known as an effective strategy for conserving water and increasing yield without reducing crop quality (Ma *et al*., 2019).

“To use the water resources more efficiently, the partial root-zone drying (PRD) technique was introduced” (Demir *et al*., 2022). These approaches are an effective strategy to increase irrigation water productivity. Numerous studies have shown that the DI and PRD strategy's slow soil drying generates physiological reactions in potato plants throughstomatal closure (Jensen *et al*., 2010).Numerous experimental findings suggest that water stress at two stages—namely, vegetation and tuber growth—had a significantly detrimental impact on potato yield compared to the tuber bulking and maturation stages (Hassan *et al*., 2002; Mahima *et al*., 2018).According to Patanè *et al*. (2011), a greater level of DI resulted in a water savings of 46.2%, an improvement in the amount of soluble solids, and had no appreciable impact on the marketable yield. Despite the widespread study of the DI strategy in various parts of the world, Iran's semi-arid regions have few similar studies. According to our literature review, there is insufficient knowledge of the simultaneous effects of DI - PRD, cultivar, and irrigation methods on potato yield. In order to determine how the DI strategy affects the WUE, water productivity (WP) as crop per drop (CPD), growth, and productivity of various potato cultivars, a complete experiment has been done in the semi-arid soil of the Shahrekord region of Chaharmahal-Va-Bakhtiari Province, Iran.

MATERIALS AND METHODS

Characterization of the study site

The Char Takhte research station was selected to do this study in June to October 2013 and 2014. The station is located in Chaharmahal-va-Bakhtiari Agricultural and Natural Resources Research Center, Iran. The study area is approximately 6000m^2, which is located at 32˚18′00" N and 50˚55′00" E. The area has an elevation 2090 m above sea level. During a 20 years (2001-2021), the average total amount of precipitation recorded during a year is 322.1 mmand temperature is 11.3 °C.

Experimental design

To assess and compare the effects of DI - PRD, cultivar, and irrigation methods, the split-split-plot experiment was done with three replications as Randomized-Complete-Block-Design (RCBD). Treatments were (1) two irrigation methods, (2) two potato cultivars and (3) four deficit irrigation strategies. The main plots were the irrigation methods (S1= furrow irrigation, S2= tape drip irrigation), sub-plots including potato cultivars (V1= Almera cultivar, V2= Burren cultivar) and the secondary sub-plots were deficit irrigation managements (FI=100%, RDI_{80}= 80%, RDI_{65}= 65% of available water depletion (AWD), and PRD= partial root-zone drying during growth period). Therefore, 16 treatments with three replications formed 48 experimental plots. The schematic diagram of the split-split plot design was shown in Figure 1.

S2								S1								R1
V1				V2				V2				V1				
FI	PRD	R80	R65	FI	R80	PRD	R65	R80	R65	FI	PRD	R80	R65	FI	PRD	

S2								S1								R2
V2				V1				V2				V1				
R80	R65	FI	PRD	R80	R65	FI	PRD	FI	PRD	R80	R65	FT	PRD	R80	R65	

S2								S1								R3
V2				V1				V1				V2				
R65	FI	PRD	R80	FI	PRD	R80	R65	R80	R65	FI	PRD	R80	R65	FI	PRD	

Figure. 1. *The schematic diagram of the split-split plot design.*

Crop water requirements and scheduling of irrigation

The crop water requirement was determinedusing the soil moisture. In each irrigation cycle with the aim of replacing soil moisture in the depth of root development up to the agricultural capacity, the net depth of irrigation for FI treatment (100% of AWD) was determined based on the following equation (Gupta *et al*., 2019):

$$dn = (\theta_{fc} - \theta_i) \times \rho_b \times Z_r \qquad (1)$$

where dn: net depth of irrigation (mm), θ_i : soil moisture before irrigation (% weight), θ_{fc}: soil moisture at FC (% weight), ρ_b: bulk density (gcm^{-3}) and Z_r :root depth (mm).
Irrigation scheduling was done based on calculating moisture reduction in adequate root depth up to readily available moisture. The lower level of readily available moisture (allowable depletion) was determined using the following equation (Allen*et al*., 1998):

$$\theta_m = \left[\theta_{fc} - MAD(\theta_{fc} - \theta_{pwp})\right] \qquad (2)$$

where θ_m, θ_{fc}, θ_{PWP} and MAD are the lower level of readily available moisture, soil moisture at FC –PWP and the maximum allowable depletion, respectively. The MAD is equal to 50% for potato (Allen*et al*., 1998).

The wateramount used in each irrigation cycle was calculated in this study by monitoring the soil moisture at the time of irrigation and applying equation 1 to the full irrigation and PRD treatments.The amount of water utilized for each approach was then calculated based on the size of each plot and the irrigation efficiency. The amount of water consumed for the deficit irrigation management's treatments was set as a coefficient of its amount in the complete irrigation treatment. The root depth in complete irrigation and PRD was measured during growth season at different irrigation as random samples by digging a trench next to the plant. Irrigation interval was considered based on the 50% of MAD at full irrigation treatment and maximum daily evapotranspiration. Irrigation interval in furrow and tape drip irrigation was 7 and 4 days, respectively. In the complete irrigation treatment, the amount of soil moisture was always higher than the amount that readily available moisture at irrigation time.
Time of irrigation in furrow irrigation was calculated based on the required time for water penetration as following equation (Phocaides and FAO, 2000):

(3)

$$T_I=T_A+T_n$$

where TI is the total irrigation time, TA and Tn are advance time and required time for net irrigation depth at the end of the furrow, respectively. Then, gross application depth was calculated according to the following equation (Phocaides and FAO, 2000):

(4)

where, I_g, Q, T_I, W and L are gross depth applied (mm), inflow rate to furrow (Ls^{-1}), total irrigation time (min), furrow spacing (m) and furrow length (m), respectively.

The irrigation time in the tape drip irrigation was obtained from the following relationship (Phocaides and FAO, 2000):

$$(5)\ T_t=\frac{I_n \times A}{q_t}$$

Where, T_t is irrigation time (h) and I_n, A and q_t are net depth of irrigation (mm), area (m^2) and inflow rate of tape (Ls^{-1}), respectively.

To ensure from the method of calculating the crop water requirement according to the amount of soil moisture deficiency, in this research, the evaporation and transpiration of the potato was also calculated using the evaporation pan method. Evaporation data from the class A pan which was located in the agricultural meteorological station in the study area (Monte *et al*., 2013) was used to determine the ET_0 based on the following equation (Phocaides and FAO, 2000) :

$$(6)\ ET_0=K_pEpan$$

WhereET_0: reference evapotranspiration (mm/day), K_p: pan coefficient and E_{pan}: pan evaporation (mm/day).

The $K_p$related to the location of pan and the condition of surroundings area (i.e., with or without ground cover vegetation andclimatic parameters). In this study, based on the wind speed and relative humidity, the K_p was considered equal to 0.55. The $ET_c$of potato was calculated based on ET_0 value and crop coefficient (kc) at each growth stage. The kc valuesfor potato at different stages were 0.45 (initial), 0.75 (development), 1.15 (mid- season) and 0.85 (late- season).

Water use efficiency

In this study,by dividing the yield of each treatment by total water used,the WUEwas calculated. The WP was calculated as a yield to irrigation water ratio. (Fernandez *et al*., 2020).

The yield components

"Fresh leaf samples were selected from each treatment.The proline content was determined according to the Bates *et al*. (1973) method and then measured using a spectrophotometer at 520 nm" (Saad *et al*., 2023). From each plot, four plantsat final harvestwere selected. Then, all plant materials were harvested, removed from soil and placed in a plastic bag. To determine the overall yield for each treatment, all tubers were cut free from their roots, counted, and weighed.In order to determine the tuber dry matter, tubers were dried (at 105 $^{\circ}$C for 24 h) and finally the dry mass was weighed.

Statistical analysis

Analysis of variance (ANOVA) among 16 treatments was performed, and the mean comparison was done using the Duncan test. The SAS software (version 9.4) was used to performe the analysis.

RESULTS

Effects of deficit irrigations on yield

Table 1 shows the ANOVA of a split-split-plot for potato yield, tubers quality and WUE as influenced by cultivars, irrigation methods and different DI. Results showed that although the impact of year on tuber yield was not statistically significant, this property significantly impacted by the type of irrigation at $p < 0.05$ (Table 1). The tape drip irrigation method had the highest output (44.7 $tonha^{-1}$), and it also increased the production by 5% while using 42% less water. The uniform water distribution, precise control of water volume, and decreased evapotranspiration are all factors that contribute to the higher yield with drip irrigation.

The most efficient method of giving plants direct access to water and nutrients is through drip irrigation.When using drip irrigation, water is contained in the roots of the plants and given in small amounts to meet their daily needs, resulting in a plentiful crop of high quality.

The installation of drainage pipes for each row of potato cultivation in this research is another factor that has increased the production when using the tape drip irrigation method, since this has made enough moisture available to the plant's root zone. Ma *et al*. (2021) explained that the grain yield was higher in drip irrigation than surfer method because this method get better water distribution in the root area.Zhang *et al*. (2021) confirmedsignificant effects of irrigation methods on the grain yield, water consumption and water productivity.

Also, these researchers indicated the lesser reduction in yield induced under drip irrigation. Results indicated that differences of tubers yield between cultivars were significant ($P \leq 0.01$), with the Burren cultivar recording the maximum yield (47.8 $tonha^{-1}$) (Table 2). Compared to the Almera cultivar, the Bourne cultivar generally enhanced yield per unit area by 16.7%. (Table 2).

Results declared that the influence of DI was significanton tubers yield at $P \leq 0.01$ (Table 1) and the highest – lowest tubers yield with 52.8 and 25.5 $tonha^{-1}$ wasdisclosed and RDI_{65} treatments, respectively (Table 2). In this study, tubers yield reduced noticeably by 8% in plants receiving 80% IR and PRD irrigation and by 52% in plants receiving RDI_{65} irrigation. Consequently, DI significantly decreased the yield of tubers (Table 2). This decrease may be attributable to the influence of water stress on the plant's metabolism and amount of photosynthetic activity. The drought conditions significantly influenced the nutrient availability and absorption by plants, which had a detrimental impact on production. Several researchers have found yield reductions due to ID approach (Bassouny and Abbas, 2019; Ibrahim *et al*., 2020; Amjad *et al*., 2021; Ding *et al*., 2021; Saad *et al*., 2023). Results also showed that moisture regimes and irrigation levels had a significant impact on potato yield. Additionally, a disruption in the tuber formation process brought on by water stress (i.e., the lowest irrigation level) might result in malformation and aberrant tuber growth.

Furrow and tape drip irrigation methods can each save 10 and 4% of irrigation water when PRD treatment is applied. In the PRD treatment, half of the root system is subjected to drying while the other half receives regular irrigation. In order to prevent water loss from the leaves and shoots, the plant roots in drying soil transmit a chemical signal to them through the xylem, such as abscisic acid (ABA). As a result, the stomata may close and the water loss is stopped.Additionally, a slight constriction of the stomata opening may significantly reduce water loss with no effect on photosynthesis. Numerous studies showed that "the PRD can reduce water use and increase WUE without significantly reducing crop yield" (Liang *et al*., 2013; Chen *et al*., 2016; Al-Kayssi, 2023). According to Al-Kayssi (2023), the use of an alternative partial root-zone drying technique decreased maize's conventional irrigation water use by about 20%, increased the amount of dry matter that shoots and roots by an average of 20%, and increased WUE by 50%.

Table 1- The analysis of variance (ANOVA) of a split-split-plot for yield, quality of tubers, water use effecincy and andcrop per drop of potato.

Source of variations	df	Mean Square					
		Tuber yield	Tuber dry matter	Starch	Proline	WUE	CPD
Year	1	76.8^{ns}	0.26^{ns}	0.32^{ns}	3.25^{ns}	13.8^{**}	7.8^{*}
Error	4	10.2	0.05	0.06	0.79	0.8	0.4
Irrigation methods (a)	1	105.0^{*}	0.06^{ns}	0.27^{ns}	2.73^{ns}	29.0^{**}	745.6^{**}
Year* a	1	1.3^{ns}	1.63^{ns}	0.03^{ns}	6.65^{ns}	0.3^{ns}	$^{ns}0.1$
Error a	4	7.0	0.26	0.1	0.94	0.5	0.3
Cultivar (b)	1	1547.8^{**}	240.3^{**}	1.75^{*}	12.61^{ns}	132.9^{**}	85.2^{**}
Year* b	1	43.6^{ns}	0.5^{ns}	0.01^{ns}	1.7^{ns}	4.1^{ns}	$^{ns}2.5$
a*b	1	$^{ns}44.1$	0.01^{ns}	0.03^{ns}	0.01^{ns}	10.5^{*}	14.6^{**}
Year*a* b	1	0.4^{ns}	0.01^{ns}	0^{ns}	0.15^{ns}	0.2^{ns}	$^{ns}0.3$
Error b	8	27.8	0.76	0.18	2.81	1.8	0.9
DI	3	3679.9^{**}	48.85^{**}	39.95^{**}	264.8^{**}	180.8^{**}	113.5^{**}
Year* DI	3	3.3^{ns}	0.66^{ns}	0.38^{ns}	0.85^{ns}	0.5^{ns}	0.2^{ns}
DI* a	3	0.5^{ns}	0.27^{ns}	0.07^{ns}	0.67^{ns}	2.5^{**}	6.8^{**}
Year* a* DI	3	1.7^{ns}	0.32^{ns}	0.27^{ns}	0.35^{ns}	0.1^{ns}	$^{ns}0.1$
DI* b	3	30.5^{**}	0.01^{ns}	0.23^{ns}	1.14^{ns}	2.0^{**}	1.2^{**}
DI* a*b	3	0.4^{ns}	0.29^{ns}	0.17^{ns}	0.62^{ns}	0.1^{ns}	$^{ns}0.14$
Year* b* DI	3	$^{ns}1.6$	0.18^{ns}	0.24^{ns}	0.87^{ns}	0.1^{ns}	$^{ns}0.1$
Year* a* b* DI	3	2.7^{ns}	0.12^{ns}	0.16^{ns}	0.41^{ns}	0.3^{ns}	0.2^{ns}
Error c	48	4.8	0.56	0.19	0.68	0.3	0.2
Coefficient of variation (CV)		5.0	3.7	3.1	4.13	4.6	4.4

n.s. :no statistically significant difference, * and ** represent the statistically significant difference at $P \leq 0.05$ and 0.01, respectively.

Table 2. Mean comparison results for different treatments on yield, quality of tubers, water use effecincyand andcrop per drop of potato

Treatment		Tuber yield ($ton ha^{-1}$)	Tuber dry matter (%)	Starch (%)	Proline ($mg g^{-1}$)	WUE ($kg m^{-3}$)	CPD ($kg m^{-3}$)
Year	First	44.7^{a}	20.04^{a}	13.89^{a}	20.08^{a}	12.87^{a}	10.12^{a}
	Second	42.9^{a}	20.14^{a}	14.00^{a}	19.71^{a}	12.08^{b}	9.54^{b}
Irrigation methods	Furrow	42.8^{b}	20.11^{a}	13.89^{a}	20.07^{a}	10.94^{b}	7.04^{b}
	Tape drip	44.9^{a}	20.06^{a}	14.00^{a}	19.73^{a}	14.42^{a}	12.62^{a}
Cultivar	Almera	39.8^{b}	18.50^{b}	13.81^{b}	19.53^{a}	11.33^{b}	8.89^{b}
	Burren	47.8^{a}	21.67^{a}	14.08^{a}	20.26^{a}	13.61^{a}	10.77^{a}
DI	FI	52.8^{a}	18.67^{c}	15.39^{a}	15.87^{c}	12.64^{c}	10.08^{c}
	RDI_{80}	48.5^{b}	19.83^{b}	13.92^{c}	19.96^{b}	13.81^{a}	10.94^{b}
	RDI_{65}	25.5^{c}	22.07^{a}	12.26^{d}	24.00^{a}	8.46^{d}	6.70^{d}
	PRD	48.5^{b}	19.79^{b}	14.19^{b}	19.76^{b}	14.5^{a}	11.59^{a}

Different letter in an each column are statistically significant different ($P \leq 0.05$)using Duncan's test.

The effects of cultivar and DI was significant ($P \leq 0.01$) on the tubers yield (Table 1). The mean comparision showed that the highest and lowest tubers yield wih 57.3 and 23.1 $ton ha^{-1}$ were related to the Burren cultivar - FI and Almera cultivar- RDI_{65} treatments, respectively (Figure 2- A). Additionally, across all DI treatments, the Burren cultivar- FI produced the most tubers. Because of the scarcity of water resources and the high water needs of the potato, one of the most significant crops for food production, it is essential to adopt strategies to get the most out of the water resources that are already available while also ensuring the sustainability of this product's production. The introduction of a cultivar or cultivars that are less susceptible to reduced irrigation and have acceptable performance under low irrigation settings is one of the conceivable approaches to proper use water resources that are now available. The Burren cultivar, which outperformed the Almera cultivar in terms of yield and water stress tolerance, is advised for planting in dry and semi-arid regions.

Interactions between irrigation methods and DI on tubers yield were insignificant (Table 1). The largest tubers yield with 54 $ton ha^{-1}$ was associated with the tape drip-FI treatment, according to a comparison of the yield in two irrigation methods under different DI treatments (Figure 2-B). Regarding the effects of irrigation methods and cultivars on tubers production, it was discovered that the treatments using tape drip-Burren cultivar-FI and furrow-Almera cultivar-RDI_{65} had the highest and lowest tubers yields, with 59.1 and 22.9 $tonha^{-1}$, respectively (Figure 2-C). Although this interactions was also insignificant. As a result, for the best use of water and to increase the WUE, the correct irrigation strategy (RDI_{80} and PRD), the right irrigation method (tape drip), and the modification and selection of suitable plant cultivars based on the environmental conditions of plant growth (with a short growing period and resistant to drought) are all required.

Effects of deficit irrigations on quality of tubers

Results showed that although the effects of year and irrigation type on the dry matter content (DMC) of tubers and starch were not significant, the effect of cultivar was significant at $P \leq 0.01$ (Table 1). The Burren cultivar had the highest DMC and starch values i.e., 21.67% and 14.08%, respectively (Table 2). An important element that influences the use of potatoes in food processing is their DMC in various potato varieties (Wang *et al*., 2023). The effect of DI treatment on DMC was significant at $P \leq 0.01$ (Table 1). Therefore, the DMC of tubers reduced from 22.07 to 18.67 by increasing the irrigation water from 65% to 100 significant for the DMC of tubers and starch (Table 1).

It may be concluded that the Bourne cultivar is suitable for food processing. Two %. Additionally, under these circumstances, the starch percentage rose from 12.26 to 15.39. (Table 2). Results confirmed that the interactions effects of different treatments were not

treatments, RDI_{80} and PRD, are suggested to boost the DMC % of tubers while keeping their economic performance and high quality. Because there is more tuber DMC when there is water stress in the potato, the quality of the chips likely to be better, making them suitable for the industry (Elhani *et al*., 2019). Results declared that the amount of proline was not significantly influenced by year, irrigation type and cultivar (Table 1). According to the mean comparison, the highest content of proline with 20.07 and 20.26 mgg^{-1} was related to furrow irrigation and Burren cultivar, respectively (Table 2). Results declared that DI had significant effects on proline content at $P \leq 0.01$ (Table 1). The content of proline was strongly affected by the DI management and with increasing water stress, the amount of proline increased (Table 2). The concentration of proline increased from 15.87 to 0.24 mgg^{-1} when irrigation water was reduced from 100% to 65%. By stabilizing subcellular structure and acting as an osmotic adjustment, proline increases a plant's tolerance to water stress. Proline has been shown in numerous studies to increase plants' tolerance to a variety of environmental stressors (Fahad *et al*., 2015; Semida *et al*., 2020; Saad *et al*., 2023). According to Saad *et al*. (2023), the deficit irrigations significantly increasedproline in wheat shoots. So, proline content can be used to measure a plant's ability to withstand drought. The conclusion drawn from this study's findings is that the furrow irrigation method places the potato plant under additional stress. Additionally, compared to the Almera cultivar, the Boren cultivar is more drought resistant.

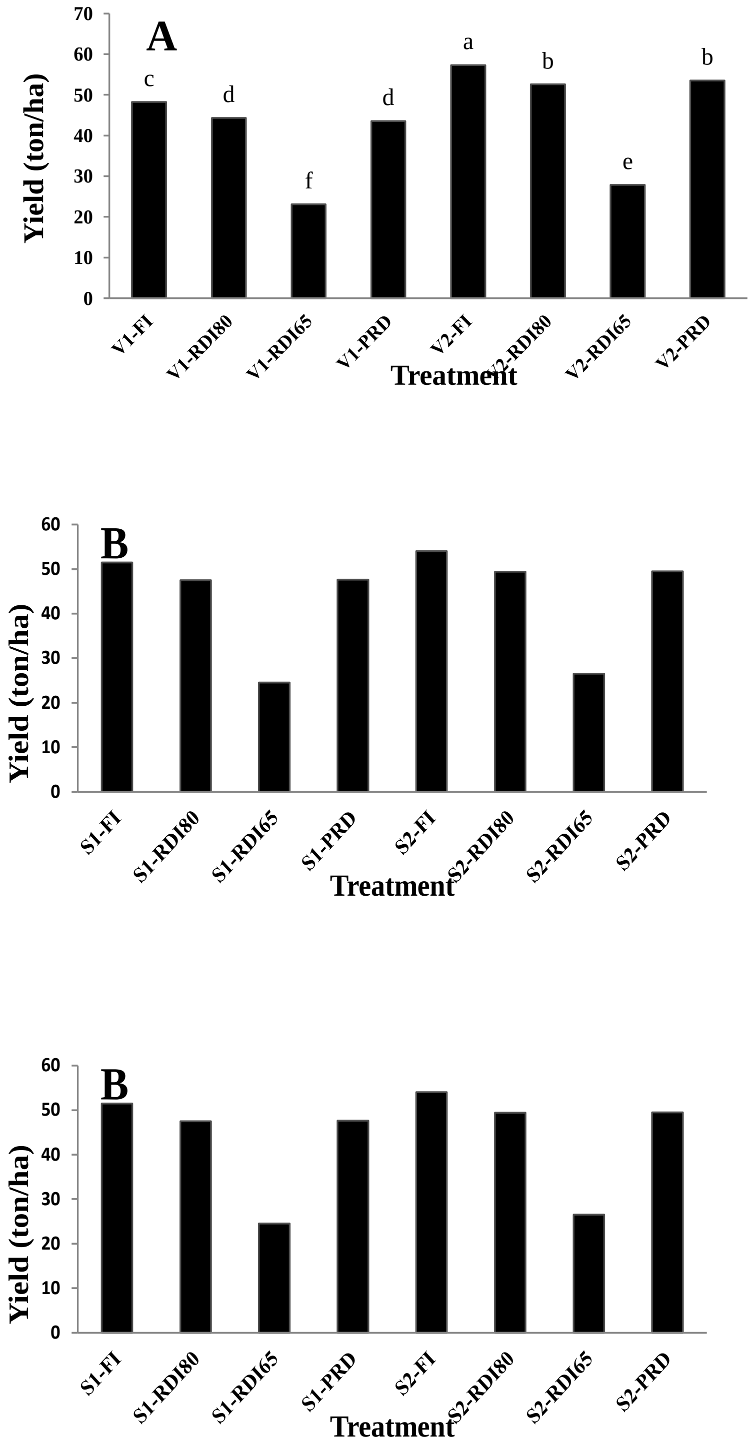

Figure. 2.The interaction effects of (A): cultivar and DI, (B): irrigation types and DI and (C): irrigation types and cultivar on the yield.

Effects of deficit irrigations on WUE and CPD

Results demonstrated that the effects of various irrigation methods, cultivars and DI were significant ($P \leq 0.01$) on WUE and CPD (Table 1). When compared to furrow irrigation, the WUE was 32% higher using tape drip irrigation (Table 2). According to the results of this study, improving irrigation techniques appears to have a major impact on raising the WUE in agriculture. Since water supplies have been limited in recent years, it is therefore vital to increase production by raising the yield per unit of water spent. As a result, more thought should go into irrigation design using techniques with high WUE, like tape drip irrigation. Since low irrigation and the proper amount of irrigation can be applied at each growth stage with tape drip irrigation, it is possible to increase the WUE. According to Al-Kayssi *et al*. (2023), DI increased the WUEup to 38.93 and 14.94% when compared to traditional watering".

Furthermore, the results explained that the Burren cultivar had the highest WUE (i.e., 13.61 kgm^{-3}), which was 20% higher than that of the Almera cultivar. Additionally, the means comparison revealed a relationship between the PRD and RDI_{65} for the highest and lowest values of WUE with 14.5 and 8.46 kgm^{-3}, respectively (Table 2). Adopting appropriate water management that delivers enough output with significant water savings is required in circumstances of water constraint. In the PRD method, the root system in drying soil can respond physiologically to water stress by releasing a chemical signal to decrease water loss. The WUE of agricultural output can be improved by PRD, according to some researches, without significantly reducing yield (Liang *et al*., 2013; Chen *et al*., 2016; Al-Kayssi *et al*., 2023).The interaction effect of irrigation type and cultivar was significant ($P \leq 0.05$) on the WUE (Table 1). The tape drip-Burren cultivar with 15.76 kgm^{-3} recorded the highest WUE (Figure 3-A). Regarding the interactions between irrigation methods and DI, our findings showed that the furrow-RDI_{65} treatment had the lowest WUE values (4.71 kgm^{-3}) and the tape drip-PRD treatment had the highest WUE values (16.47 kgm^{-3}) (Figure 3-B). At $P \leq 0.01$, these differences were considered significant.

In order to address the issue of rising WUE, attention should not only be focused on the water sector of the economy, but also on other areas like agriculture and plant nutrition. Along with water-saving measures, the plant is a crucial component of these strategies and solutions for improving performance. Therefore, the simultaneous attitude of reducing water consumption and increasing performance to increase the WUE is a more scientific and practical approach to achieve the goals of development programs in the country, which has been paid attention to in this research. The researched cultivars can therefore be a suitable replacement for Marfonaand Agriacultivars given the high efficiency of water consumption in the tested cultivars to deal with the water crisis and increase the quantity and quality of agricultural production by selecting the proper irrigation technique, managing the lack of irrigation, and correcting and selecting suitable plant cultivars.

Additionally, the outcomes demonstrated that tape drip irrigation enhanced the CPD score by 79% as compared to furrow irrigation (Table 2). According to several research, the DI can increase the WUE and decrease irrigation water use without affecting plant dry mass or yield

(Adu *et al*., 2018; Al-Kayssi, 2023; Ma *et al*., 2023). Also, the means comparison showed that the highest values of CPD with 10.77 kgm^{-3} was related to the Burren cultivar and this cultivar increased the CPD by 21% compared to the Almera cultivar (Table 2). The means comparison showed that the highest and lowest values of CPD with 11.59 and 6.7 kgm^{-3} was related to the PRD and RDI_{65}, respectively (Table 2). The PRD method encourages the growth of secondary roots in particular, increases root density, and allows roots to penetrate deeper soil layers. Finally, the capacity of plantscan profoundly affected by changing root morphology to absorb water and nutrients. Previous research demonstrated that PRD can enhance root development (dos Santos *et al*., 2007; Abrisqueta *et al*., 2008; Liu *et al*., 2020).

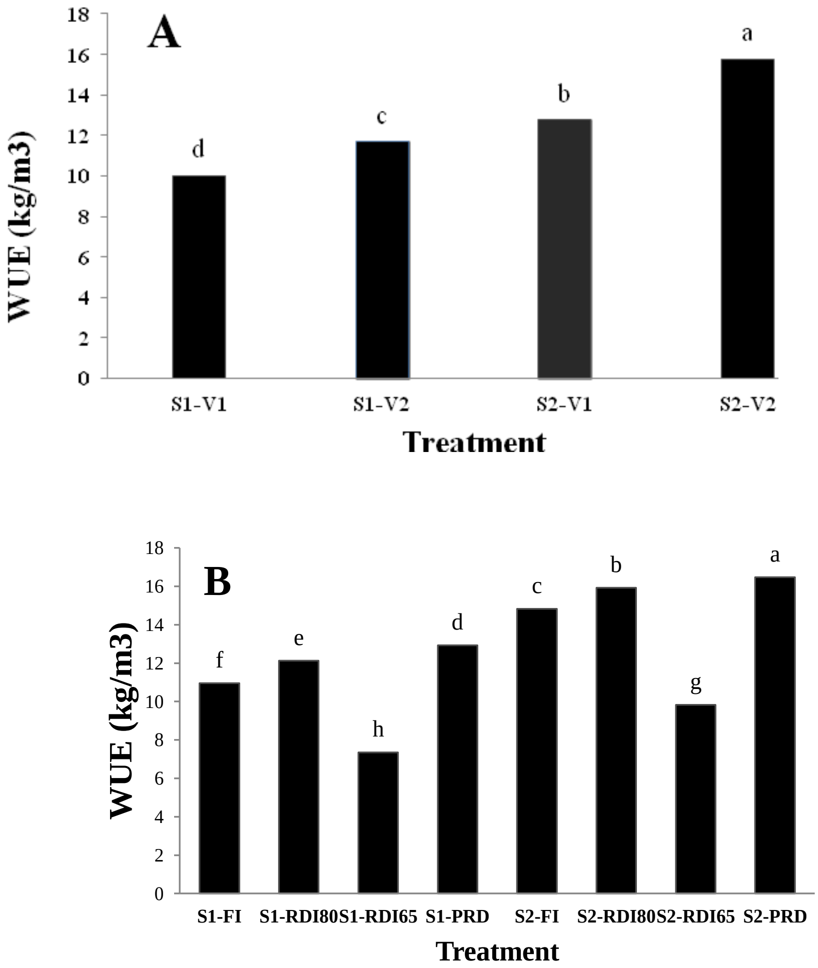

Figure 3. The interaction effect of (A): irrigation types and cultivar and (B): irrigation types and DI on the water use efficiency.

The simultaneous effects of irrigation type and cultivar was significant on the CPD (Table 1). The tape drip-Burren cultivar with 13.95 kgm^{-3} recorded the highest CPD values (Figure 4-A). Concerning the interactions between irrigation types and DI, our results revealed that the highest values of the CPD (i.e., 14.57 kgm^{-3}) were recorded for tape drip- PRD treatment while the lowest values of the WUE (i.e., 4.71 kgm^{-3}) was related to furrow- RDI_{65} treatment (Figure 4-B). These differences were significant at P ≤0.01. The physiological and morphological changes to the roots that take place while using PRD procedures are advantageous for allowing the plant to absorb water and nutrients. Additionally, the frequency of the alternated moist and dry sides of the root system varies depending on the stage of plant growth. The interaction effect of cultivar and DI was significant (P ≤0.01) on the CPD (Table 1). The highest values of the CPD (i.e., 12.83 kgm^{-3}) were recorded for Burren cultivar - PRD treatment while the lowest values of the CPD (i.e., 6.02 kgm^{-3}) was related to Almera cultivar- RDI_{65} treatment (Figure 4-C). Therefore, it is essential to select the irrigation method (tape drip) in accordance with the environmental parameters of plant growth in order to use water efficiently and enhance production per unit of water consumed.

CONCLUSION

The effects of DI managements as 65 and 80% irrigation requirement versus 100% irrigation and PRD were evaluated under various irrigation methods on potato yield, its quality and WUE and WP. The tape drip irrigation method had the highest output (44.7 $tonha^{-1}$), and it also increased the production by 5% while using 42% less water. The uniform water distribution, precise control of water volume, and decreased evapotranspiration are all factors that contribute to the higher yield with drip irrigation.In comparison to the Almera cultivar,the Bourne cultivar generally enhanced yield per unit area by 16.7%.Furrow and tape drip irrigation methods can each save 10 and 4% of irrigation water when PRD treatment is applied. Because of the scarcity of water resources especially in the regionsthat receive low precipetation and the high water needs of the potato, one of the most significant crops for food production, it is essential to adopt strategies to get the most out of the water resources that are already available while also ensuring the sustainability of this product's production. The introduction of a cultivar or cultivars that are less susceptible to reduced irrigation and have acceptable performance under low irrigation settings is one of the conceivable approaches forproper use of the water resources that are now available. The Burren cultivar, which outperformed the Almera cultivar in terms of yield and water stress tolerance, is advised for planting in dry and semi-arid regions.

Key findings from this study can be described as:

1- Tape Drip Irrigation Method: The tape drip irrigation method resulted in the highest potato yield of 44.7 ton/ha. It increased production by 5% compared to other irrigation methods. Moreover, this method achieved this while using 42% less water due to its advantages of uniform water distribution, precise control of water volume, and reduced evapotranspiration.

2- Cultivar Comparison: The Burren cultivar showed better performance than the Almera cultivar, with a 16.7% increase in yield per unit area.

3- Water Savings with PRD: Both furrow and tape drip irrigation methods can save 10% and 4% of irrigation water, respectively, when PRD treatment is applied. PRD is a water-saving technique that can help mitigate water scarcity, especially in regions with low precipitation.

In summary, the research suggests adopting water-efficient irrigation methods like tape drip irrigation and implementing deficit irrigation strategies to optimize potato yield and water use. Additionally, selecting suitable potato cultivars with better water stress tolerance can contribute to the sustainable use of available water resources in regions facing water scarcity.

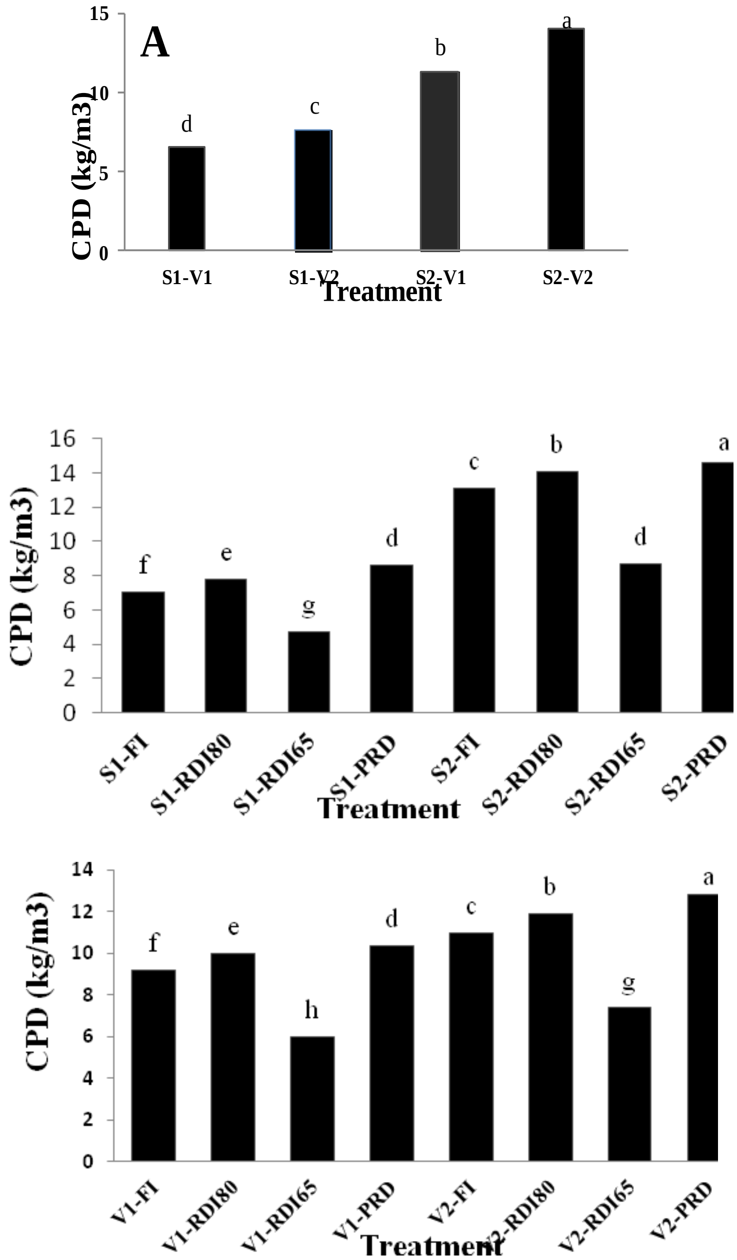

Figure. 4. The interaction effect of (A):irrigation types and cultivar, (B): irrigation types and DI and (C): cultivar and DI on the CPD.

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