Effects of different irrigation methods and hormone application on water use efficiency, yield, and leaf biochemical traits in potato

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Abstract

Investigation of different irrigation methods on plants is necessary due to limited water resources and the increasing need for food products. The purpose of this study was to evaluate the effect of sprinkler and drip irrigation systems and hormones on morphological and physiological characteristics of potato. Treatments included sprinkler and drip irrigation systems and hormones (gibberellic acid, acetylsalicylic acid, epi-brassinolide, and no use of growth regulators) as split plot based on randomized complete block design with three replications during 2015 and 2016 growing seasons at a research farm located in Malayer. Results showed that the highest level of tuber dry matter (TDM) was related to epi-brassinolide hormone + drip irrigation after using 80% of the field capacity (FC) in 2015 and epi-brassinolide hormone + drip irrigation after using 70% of the FC in 2016. The lowest amount of water use efficiency (WUE) was seen in sprinkler irrigation + no use of regulators in both years. The highest value of WUE was seen in epi-brassinolide hormone along with drip irrigation after using 80% the FC and drip irrigation after using 70% of the FC in 2015 and also in epi-brassinolide hormone + drip irrigation after using 70% of the FC in 2016. There were high and significant correlations between water use efficiency and relative water content with morphological characteristics. In order to increase the production and potato water use efficiency in cold dry climate, drip irrigation along with epi-brassinolide hormone is recommended.

Keywords: drip irrigation; Epi-brassinolide; water use efficiency; Tuber dry matter

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Introduction

Potato crop (*Solanum Tuberosum* L.) is very sensitive to water irrigation methods and the available soil water should not be reduced by more than 30-50% of FC (Ferreira 2002). This sensitivity can be attributed to its small and shallow root system. In recent decades, water deficit stress is one of the most important limiting factors for field crops that adversely affect plant growth and yield productions. Many irrigation experiments have shown that limited soil water availability decreases plant growth tuber yield, the number of tuber per plant, by limiting transpiration and photosynthesis and increasing plant temperature (Yuan et al., 2003; Hassan panah., 2010).

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Table 1
Soil physical and chemical properties of the sample collected from site study

0-40cm	pH	EC (dS m^{-1})	TN%	OC%	N%	P (Mg/Kg^{-1})	K (ppm)	BD (Mg m^{-3})
2015	7/3	0.4	5.5	0.2	0.02	4	247	1.3
2016	7.4	0.3	6	0.4	0.05	7	258	1.3

EC : Electrical conductivity; TN: Total nitrogen; OC: Organic matter; BD: Bulk density

Water saving may be achieved with drip irrigation and even improved results seem to be possible with partial root zoon drying and these methods have been tested on many crop species. While sprinkler irrigation methods are widely used in potato production in Iran, drip irrigation has not been as widely used in potato production in the region because of the greater price of drip line installation. Insufficient or excess of water supply leads to reduced growth rate of foliage, incomplete ground cover, and reduced interception (Tourneux, 2003). Water stress increases sprouting and malformation, but decreases plant growth, tuber yield, number of tuber per plant, and the size of tubers which leads to tuber defects such as internal grown spot especially when foliage is dead and soil is exposed to the sun. (Levy and Veilleux, 1986; Schaflei, 2007).

Previous studies showed that limited soil water decreases plant growth and tuber yield, number of tuber per plant. However, little information is available about the water use efficiency, growth, and yield of potato with farm drip and sprinkles irrigation in Iran. Many studies have revealed that these hormones invoke responses in both mature and young leave. Some protein families serve as an interface of plant hormones, suggesting a pivotal functional involvement of lipid derived signaling in abiotic stress responses (Golldack et al., 2014). Application of exogenous gibberellic acid (GA) was found to increase not only foliage but also tuberization. It has been reported that application of GA in the shoots of potato plant increased the partitioning of dry matter to the shoots without preventing tuber formation. Brassinosteroids and acetil salicylic acid are natural substances which are essential for plant growth and development. It is well documented that these hormones can induce a broad spectrum of responses among plants, including stem elongation, leaf epinasty, and yield increase. Most studies have focused on relieving or overcoming stresses related to drought or temperature. For example, epi-brassinolide treatment enhanced tolerance of tomato and brome grass to high temperature (Singh and Shono, 2005; Wilen et al., 1995). Sarian (1994) found that homobrassinolide significantly increased the relative water content, chlorophyll content, photosynthesis rate, leaf area, and biomass production of wheat under water stress.

The objective of this research was to evaluate the effects of surface and drip irrigation methods and foliar application of gibberellic acid, epi-brassinolide, and acetyl salicylic acid on yield and yield components of potato in Iran. Nowadays, subsurface drip irrigation is also under evaluation to improve water use efficiency since water is getting scarce and more valuable.

Materials and Methods

A two-year field study was conducted at Malayer, Hamedan, Iran (48′, 82° E and 34′, 29° N and the height of 1725 m above sea level). The site is located in a temperate arid zone with mean annual precipitation of 300 mm. The climate data for the two years are shown in Table 1. All plots were harrowed twice prior to planting on 30th April each year. Potato seed pieces (the medium-late potato (*Solanum tuberosum* L.) cultivar ‘Banba’) were hand-cut to average weight about 30 g per seed piece, and planted to the field plots on 24 and 29th May 2015 and 2016, respectively at about 0.1 m depth below the soil surface with a six-row planter. Two weeks before planting, soil samples were taken in order to determine and test for pH, electrical conductivity (EC), organic carbon through sulfuric acid using the Walkley and Black (1934) method, total N by the Kjeldahl Method, available P by the Olsen procedure (Olsen, 1982), and available K after extraction with ammonium acetate (Tandon, 1995). The soil type was silt loam, the bulk density of the soil was 1.3 Mg m^{-3} and soil pH value was 7.3. Each experimental unit was 9 m long and consisted of 8 rows spaced 0.7 m apart with 0.25 m spacing between plants in a row. There were 2 m gaps between the blocks, and 1 m alley was established between each plot to prevent lateral water movement and other interferences. The density of plants was 8/m^2. For each plot, a balance sheet for the NPK, based on soil analysis was developed. Thirty percent of N and total P and K requirements were supplied (NPK in the form of urea, superphosphate triple, and potassium, respectively) at planting. For the rest of the season urea was used.

The first factor (which consisted of two drip irrigation methods) included seven irrigation regimes. The methods were sprinkler irrigation (SI) and surface drip (SD) irrigation methods in six levels as a main plot. Sprinkler method which is common method in Iran was compared with treatments exposed to water-saving through the application of surface drip (SD) irrigation methods.

For the field experiments, the plant-available soil water content (ASW) for the rooting depth was calculated as:

$$ASW = (AS-WS)/(FC-WS)$$

where FC, AS, and WS are field capacity, actual soil water content, and soil water content at wilting point, respectively. For the two years, the crop water use was calculated as kc × ETp, where kc is the crop-coefficient and ETp is the potential evapotranspiration

The irrigation levels were SI (irrigation initiated after using 80% of the FC, well-watered), SD1 (irrigation initiated after using 80% of the FC, well-watered), SD2 (irrigation initiated after using 70% of the FC), SD3 (irrigation initiated after using 60% of the FC), SD4 (irrigation initiated after using 50% of the FC), SD5 (irrigation initiated after using 40% of the FC) and SD6 (irrigation initiated after using 30% of the FC).

The second factor included four spaying treatments as a subplot. The foliar application levels were non foliar application (H_1, control), gibberellic acid (H_2), epi-brassinolide (H_3), and acetylsalicylic acid (H_4). Irrigation treatment was supplied after emergence and lasted until final harvest. All foliar applications were conducted at tuber initiation. For leaf spraying, an amount equivalent to 200 mg/L, 1 mg/L, and 100 ppm of solution (gibberellic acid, epi-brassinolide, and acetylsalicylic acid, respectively) were applied using a backpack sprayer with constant pressure. Soil moisture was monitored throughout the whole vegetative period by taking soil samples at the depth of 40 cm, with a neutron probe (twice weekly). The irrigation rate was calculated for a soil depth of 40 cm. Leaf water potential and mass of the tubers were determined at the end of the growth period (late September to early October in both years when it was the usual time for harvesting potato tuber in Hamedan) on the first, fully developed leaf. Leaf area index was determined using a leaf area meter (AAM-9, Hayashi Denko, Tokyo, Japan). Percentage of leaf water saturation deficit (WSD) in 4th leaf counting from top was determined as described by Turner (1981). Ten leaves were cut from each plot at 8.00 a.m., weighed immediately (for fresh weight, FW), floated in the dark for 24 h to achieve turgidity (turgid weight, TW), then oven-dried (105° C) for 24 h and weighed again (dry weight, DW). The WSD of leaves was calculated as follows:

$$WSD = [(TW - FW)/(TW - DW)] \times 100\%.$$

Relative water content (RWC) was calculated as follows:

$$RWC (\%) = (fresh\ FW-DW)/(TW-DW) \times 100.$$

The middle four rows in each plot were harvested by hand on rd3 October and 27th September in 2015 and 2016, respectively. Tubers were separated from the plants, counted, washed and weighed. The number of tubers per plant, tuber yield per plant, and mean tuber weight and yield were determined from 10 randomly selected plants in each subplot prior to harvest. They were then sliced, oven-dried at 90° C for 72 h, and re-weighed. Measurements were carried out on 3 repeats. Water use efficiency (WUE) was calculated by dividing the marketable yields by the volume of applied water.

Table 2
Monthly temperature and precipitation during the growing season in 2015 and 2106

Months	June	July	August	September	October
2015					
M.A.T. (◦C)	23.4	27.23	26	22.8	19.11
Rain (mm)	0	0.06	0	0.42	0
2016					
M.A.T. (◦C)	22.13	26.42	25.71	22	19
Rain (mm)	0	0	0	0	0

M.A.T. = mean air temperature; M.R. = mean rain

Table 3
Analysis of variance (mean squares) for the effects of irrigation and hormone treatments on morphological and physiology traits of potato in 2015 and 2016

SOV	df	Plant Height	LAI	LDW	WSD	No of stolen	No of Tuber	SDW	Tuber Dry Matter	Tuber Dry Weight	WUE	RWC
		First Year (2015)										
Block	2	31.10 *	0.24 **	127.85 ns	46.44 *	3.94 **	14.43 **	234.08 ns	0.59 ns	502.94 ns	0.0023 ns	71.45 **
Irrigation (I)	6	1246.01 **	6.80 **	4176.87 **	343.37 **	30.11 **	1213.50 **	15612.94 **	8.0009 **	308028.88 **	2.09 **	398.88 **
Main error	7	4.91	0.00045	100.81	7.34	0.25	2.008	104.56	0.14	209.52	0.001	9.14
Hormone (H)	3	454.39 **	1.37 **	1289.19 **	70.40 **	8.60 **	766.766 **	5101.91 **	1.98 **	38433.12 **	0.17 **	77.88 **
I × H	18	3.16 **	0.0099 **	17.54 ns	1.57 *	0.23 ns	5.52 **	29.67 ns	0.065 ns	597.28 **	0.0039 **	1.20 ns
Sub Error	126	0.92	0.00034	14.54	3.01	0.26	0.83	30.67	0.037	63.20	0.00031	0.86
CV (%)		1.22	0.63	6.64	4.78	2.29	2.03	4.42	0.92	1.26	1.32	1.18
		Second Year (2016)										
Block	2	6.38 ns	0.023 **	33.59 ns	23.27 ns	8.72 **	5.49 ns	194.56 *	0.39 ns	483.89 ns	23.27 ns	71.45 **
Irrigation (I)	6	1199.71 **	6.80 **	3169.02 **	3.555 **	21.91 **	401.27 **	12335.47 **	2.52 **	112565.84 **	355.55 **	398.88 **
Main error	7	6.85	0.0002	25.10	7.62	0.72	13.57	32.19	0.10	147.13	7.62	9.14
Hormone (H)	3	362.52 **	1.38 **	656.60 **	72.83 **	8.42 **	696.60 **	3202.68 **	0.55 **	9222.92 **	72.83 **	77.88 **
I × H	18	1.88 **	0.010 **	10.11 **	1.61 *	0.16 ns	7.65 **	22.58 **	0.02 ns	209.48 **	1.61 *	1.20 ns
Sub Error	126	0.76	0.0003	1.22	0.83	0.107	1.54	1.78	0.02	25.26	0.83	0.86
CV (%)		1.13	0.59	2.37	4.89	1.48	2.40	1.23	0.73	0.76	4.89	1.18

LIA: Leaf Area Index; LDW: Leaf Dry Weight, WSD: Water Saturation Deficit, SDW: Shoot Dry Weight, WUE: Water Use Efficiency, RWC: Relative Water Content
* and **: Significant at 0.05 and 0.01 probability levels, respectively; ns: Not significant at the 0.05 probability level

Statistical Analyses

Separate analyses were done for each year because Bartlett's test was significant for most traits measured. Analysis of variance (ANOVA) was used to evaluate the effects of the treatments on the yield and yield components and to determine the significance of the main effects and interactions for the variables measured. Least Significant Differences (LSD) test was used for comparing and ranking the treatments. Pearson correlation coefficients were calculated using the PROC CORR in SAS (SAS Institute Inc., 2002).

Results

Soil analysis before culture in 2015 and 2016

Chemical properties of soil are presented in Table 1. Soil texture was silty loam. N, P, and K contents were 0.02%, 4, and 247 ppm in 2015 and 0.05%, 7, and 258 ppm in 2016. According to Havlin et al (2005), levels of N, P, and K were low, medium, and high in both years. Soil pH was neutral and OC percentages was 0.2 and 0.4 in 2015 and 2016, respectively.

Climate conditions

Mean rain and mean air temperatures are presented in Table 2. The climate in experimental farm was semi-dry with hot, dry summers and cold winters. Highest and lowest mean air temperatures were related to 2015 and 2014. Rainfall only occurred in July 2015 with a value of 0.06 mm.

Effect of irrigation and hormone on morphological and physiological traits of potato

Results of variance analysis showed that irrigation and hormone affected morphological and physiological traits of plants in 2015 and 2016

Table 4
Effect of irrigation regimes and hormones on morphological and physiology traits of potato in 2015 and 2016

Treatment	2015					2016		
	LDW (g.m²)	RWC (%)	No of stolen (m²)	SDW (g.m²)	Tuber Dry Matter (%)	RWC (%)	No of stolen (m²)	Tuber Dry Matter (%)
SI	68.98 b	85.0 a	24.25 a	153.59 b	19.97 d	85.04 a	23.50 a	19.85 e
SD_1	67.24 b	84.1 a	24.08 a	146.18 b	20.04 d	84.10 a	23.66 a	19.92 ed
SD_2	55.75 c	79.7 b	23.00 b	121.56 c	20.61 c	79.79 b	22.50 b	20.20 cd
SD_3	45.11 d	75.9 c	22.25 c	104.02 d	20.79 c	75.91 c	21.91 b	20.44 c
SD_4	38.42 d	72.8 d	20.83 d	90.03 e	21.57 b	72.87 d	20.50 c	20.78 b
SD_5	37.70 d	70.5 d	20.00 e	81.35 e	22.15 a	70.51 d	20.16 c	21.08 a
SD_6	88.31 a	83.1 a	21.91 c	179.41 a	20.26 d	83.16 a	22.33 b	20.06 ed
H_1	48.20 d	16.6 c	21.61 d	106.62 d	20.35 c	76.23 c	21.47 c	20.17 c
H_2	58.32 b	18.4b	22.57 b	127.21 b	20.76 b	78.95 b	22.33 b	20.34 b
H_3	67.19 a	21.1 a	23.09 a	144.47 a	21.09 a	80.92 a	22.85 a	20.55 a
H_4	55.71 c	18.8 b	22.04 c	122.36 c	20.87 b	78.97 b	21.66 c	20.26 bc

LDW: Leaf Dry Weight, RWC: Relative Water Content, SDW: Shoot Dry Weight, SI: Sprinkler Irrigation, SD_1: Surface Drip after using 80% of the FC, SD_2: Surface Drip after using 70% of the FC, SD_3: Surface Drip after using 60% of the FC, SD_4: Surface Drip after using 50% of the FC, SD_5: Surface Drip after using 40% of the FC, SD_6: Surface Drip after using 30% of the FC, H_1: non foliar application (control), H_2: gibberellic acid; H_3: epi-brassinolide, H_4: Acetylsalicylic acid; means within each column followed by the same letter are not significantly different ($P \leq 0.05$).

($P<0.01$). Interaction of irrigation and hormone had significant effect on plant height, LAI, number of tuber, tuber dry weight, WUE ($P<0.01$), and WSD ($P<0.05$) in 2015. Also, there were significant differences in plant height, LAI, number of tuber, shoot dry weight, tuber dry weight, LDW ($P<0.01$), and WSD, WUE ($P<0.05$) in 2016 (Table 3). Irrigation and hormone affected morphological and physiological traits in both year, but their interaction influenced significantly some traits and the effect was in the second year was more than that in the first year.

As Table 4 shows, the greatest amount of LDW, RWC, the number of stolons, and SDW in 2015 were seen in SD_6, SI_1, SI_1, and SD_6, respectively. The lowest values of LDW and SDW in 2015 and also the number of stolons and RWC in both years were related to SD_6 treatment. The highest and lowest values of tuber dry matter in both years were seen in SD_5 and SI, respectively. There was a significant difference between SD_5 and SD_6. Amount of tuber dry matter in drip irrigation increased by 9.33% and 5.08% compared with that of the sprinkler irrigation in 2015 and 2016, respectively. F_3 treatment had the higher values of LDW and SDW in 2015 and RWC, the number of stolons, and tuber dry matter in both years as compared with the other hormone treatments. Also the lowest value was related to F1 in both years. Totally, using hormones increased morphological and physiological traits compared to the control treatment and the effect of epi-brassinolid hormone was greater.

Interaction of irrigation and hormone on morphological and physiological traits of potato

Interaction of irrigation and hormone in 2015 showed that the greatest amount of plant height, LAI, number of tubers, and tuber dry weight were related to SIH_3, SIH_2, SIH_2, and SIH_3, respectively. Besides, the highest value of WUE was seen in SIH_3 and SD_1H_3. Also, the lowest plant height, LAI, number of tubers, tuber dry weight, and WUE were observed in SD_4H_1, SD_6H_1, SD_5H_1, SD_5H_4, and SD_6H_1, respectively. In 2016, the maximum value of plant height, LAI, LDW, number of tubers, SDW, tuber dry weight, and WUE were observed in SIH_3, SIH_2, SD_6H_3, SIH_2, SD_6H_3, SD_1H_3, and SD_1H_3, respectively. The minimum plant height, LAI, LDW, number of tubers, SDW, and tuber dry weight were related to SD_5H_1. Moreover, the lowest amount of WUE was seen in SD_6H_1. In both years, the highest and lowest values of WSD were recorded in SD_5H_1 and SIH_3, respectively (Tables 5 and 6).

As Tables 5 and 6 show, the effect of drip irrigation along with hormones on most of the physiological and morphological characteristics of potato was higher than that of sprinkler irrigation. Tables 7 and 8 show high and significant correlations between morphological and

Table 5
Interaction of irrigation regimes and hormones on some traits of potato in 2015

Treatment	Plant Height (cm)	LAI	WSD	No of Tuber (m^2)	Tuber Dry Weight (m^2)	WUE (kg /m3)
SIH_1	86.3 e	3.4 f	14.4 no	51.7 ef	786.2 e	1.75 e
SIH_2	94.3 b	4.01 a	12.5 pq	67.3 a	819.3 c	1.83 c
SIH_3	96.7 a	3.9 b	10.9 r	56.7 b	875.1 a	1.95 a
SIH_4	90.8 c	3.8 c	12.8 pq	53.9 c	801.7 d	1.79 d
SD_1H_1	84.2 fg	3.1 i	15.5 lmn	50.8 ef	788.1 e	1.76 e
SD_1H_2	92.2 c	3.8 c	14.4 no	66.7 a	837.9 b	1.87 b
SD_1H_3	95.9 ab	3.7 d	11.7 qr	56.3 b	875.0 a	1.95 a
SD_1H_4	88.2 d	3.6 e	13.6 op	53.3 cd	818.7 c	1.83 c
SD_2H_1	75.8 i	2.7 l	19.8 gh	42.7 i	632.6 i	1.41 i
SD_2H_2	82.7 g	3.3 g	17.2 jk	57.7 b	711.1 g	1.58 g
SD_2H_3	84.5 f	3.2 h	16.7 kl	48.4 g	759.4 f	1.69 f
SD_2H_4	80.9 h	3.1 i	18.1 ij	45.2 h	697.0 h	1.55 h
SD_3H_1	70.2 l	2.3 n	24.7 de	35.5 mn	489.8 m	1.09 k
SD_3H_2	76.7 i	2.8 k	21.1 fg	50.6 f	561.0 k	1.25 j
SD_3H_3	80.03 h	2.7 l	19.3 hi	42.0 i	639.7 i	1.42 i
SD_3H_4	75.3 ij	2.6 m	21.2 fg	36.8 lm	556.9 k	1.24 j
SD_4H_1	61.6 o	1.8 s	27.7 b	30.7 op	422.6 p	0.94 o
SD_4H_2	68.5 m	2.3 n	23.3 e	41.6 ij	470.1 n	1.04 m
SD_4H_3	74.1 j	2.2 o	21.64 f	34.7 n	531.3 l	1.18 k
SD_4H_4	67.4 mn	2.0 q	23.5 e	31.7 o	443.1 o	0.98 m
SD_5H_1	57.07 p	1.4. u	29.2 a	27.3 q	376.1 q	0.83 q
SD_5H_2	66.9 mn	2.1 p	25.7 cd	37.7 l	434.5 op	0.96 no
SD_5H_3	70.7 lk	1.9 r	23.4 e	32.0 o	479.0 mn	1.06 lm
SD_5H_4	66.2 n	1.7 t	27.1 bc	29.8 p	422.3 p	0.94 o
SD_6H_1	72.1 k	3.0 j	16.2 klm	40.0 k	568.2 k	0.78 r
SD_6H_2	80.06 h	3.6 e	14.8 mno	52.3 de	604.7 j	0.83 q
SD_6H_3	82.8 g	3.4 f	12.7 pq	40.3 jk	630.3 i	0.87 p
SD_6H_4	76.4 i	3.2 h	15.6 lmn	40.0 k	607.9 j	0.84 q

LIA: Leaf Area Index, WSD: Water Saturation Deficit, WUE: Water Use Efficiency, SI: Sprinkler Irrigation, SD_1: Surface Drip after using 80% of the FC, SD_2: Surface Drip after using 70% of the FC, SD_3: Surface Drip after using 60% of the FC, SD_4: Surface Drip after using 50% of the FC, SD_5: Surface Drip after using 40% of the FC, SD_6: Surface Drip after using 30% of the FC, H_1: non foliar application (control), H_2: gibberellic acid, H_3: epi-brassinolide, H_4: Acetylsalicylic acid; means within each column followed by the same letter are not significantly different (P≤0.05).

physiological characteristics of potato in both years.

Finally, positive and significant correlations were seen between TDW and PH (0.916) and LAI (0.844). The correlations between TDM and PH and also LAI were 0.840 and 0.842, respectively.

Discussion

Cantore et al. (2014) and Badr et al. (2012) found that WUE of potato was significantly affected by irrigation regimes at all locations. Ayas (2013) reported that irrigation treatments had significant effects on plant height, tuber dry weight, dry matter percentage, and the number of tubers per plant at 1% probability level. Javanmardi and Rasuli (2017) stated that gibberellic acid hormone had significant effects on the number of tubers and tuber dry weight. Pazoki et al. (2012) reported that gibberellic acid and interaction of gibberellic acid and moisture had significant effects on leaf area, leaf dry matter, shoot dry matter, and RWC at P≤0.01 and P≤0.05, respectively.

However, the water contents used in drip irrigation were 10% and 20% lower than those of sprinkler irrigation in 2015 and 2016, respectively.

Table 6
Interaction of irrigation regimes and hormones on morphological and physiology traits of potato in 2016

Treatment	Plant Height (Cm)	LAI	LDW ($g.m^2$)	WSD (%)	No of Tuber (m^2)	SDW ($g.m^2$)	Tuber Dry Weight ($g.m^2$)	WUE (kg /m3)
SIH_1	85.1 d	3.45 f	52.8 g	14.2 no	53.5 efg	119.4 g	742.6 e	1.71 d
SIH_2	92.3 b	4.05 a	59.3 e	12.2 nop	69.3 a	136.5 e	760.9 cd	1.75 c
SIH_3	94.5 a	3.94 a	64.7 c	10.6 r	57.0 cd	150.9 b	802.1 a	1.84 b
SIH_4	89.6 c	3.85 c	57.3 f	12.6 mnop	54.5 ef	132.0 f	757.6 d	1.74 c
SD_1H_1	81.9 fg	3.14 i	50.3 h	15.3 lmn	52.6 fgh	114.9 h	742.4 e	1.71 d
SD_1H_2	89.4 c	3.85 c	61.2 d	14.2 no	67.6 a	137.8 e	766.7 c	1.76 c
SD_1H_3	93.1 ab	3.77 d	64.6 c	11.5 qr	56.8 cd	146.0 c	812.7 a	1.87 a
SD_1H_4	88.5 c	3.65 e	58.6 ef	13.4 lmnop	54.3 efg	133.6 f	763.0 cd	1.75 c
SD_2H_1	75.0 k	2.76 l	39.4 k	19.7 gh	51.0 hi	94.4 k	692.2 g	1.59 f
SD_2H_2	80.8 hg	3.36 g	47.5 i	17.1 jk	64.3 b	107.5 ij	733.2 f	1.68 e
SD_2H_3	83.5 e	3.27 h	53.6 g	16.5 kl	55.1 de	120.5 g	761.8 cd	1.75 c
SD_2H_4	79.5 hi	3.16 i	48.9 hi	18.0 ij	53.0 fgh	108.6 h	726.3 f	1.67 e
SD_3H_1	68.3 no	2.37 n	29.7 n	24.7 ed	46.6 kl	74.8 n	609.9 k	1.40 j
SD_3H_2	74.6 k	2.83 k	36.5 l	21.0 fg	55.2 cde	93.4 kl	635.7 i	1.46 h
SD_3H_3	77.8 j	2.75 l	41.7 j	19.2 hi	48.7 j	106.0 j	653.2 h	1.5 g
SD_3H_4	72.9 lm	2.66 m	33.5 m	21.2 fg	49.8 ij	91.9 l	634.8 ij	1.46 h
SD_4H_1	61.7 s	1.86 s	23.4 p	27.76 b	43.8 mn	61.5 o	573.1 n	1.32 k
SD_4H_2	67.1 op	2.35 n	30.5 n	23.3 e	54.1 efg	80.6 m	581.6 lm	1.33 k
SD_4H_3	72.4 m	2.28 k	36.1 l	21.6 f	46.5 l	91.4 l	617.5 k	1.42 i
SD_4H_4	65.1 qr	2.09 q	27.3 o	23.5 e	44.0 mn	78.5 m	580.6 mn	1.33 k
SD_5H_1	57.2 t	1.46 u	21.1 q	29.33 a	40.0 p	50.5 o	506.3 q	1.16 n
SD_5H_2	66.0 pq	2.41 p	27.2 o	25.7 cd	52.3 gh	62.2 o	519.5 p	1.19 m
SD_5H_3	69.0 n	1.94 r	33.7 m	23.4 e	41.7 op	75.8 n	537.4 o	1.23 l
SD_5H_4	64.3 r	1.75 t	26.9 o	27.2 bc	41.5 op	63.7 o	513.0 pq	1.18 mn
SD_6H_1	74.0 kl	3.06 j	63.2 c	16.0 klm	44.2 m	133.3 f	589.0 l	0.84 p
SD_6H_2	79.3 i	3.67 e	68.3 b	14.6 mno	57.2 c	147.9 c	617.4 k	0.88 o
SD_6H_3	82.8 ef	3.47 f	80.1 a	12.5 mnop	48.5 jk	169.3 a	626.7 j	0.89 o
SD_6H_4	77.8 j	3.28 h	63.8 c	15.4 lmn	42.1 no	142.9 d	613.8 k	0.87 o

LIA: Leaf Area Index, LDW: Leaf Dry Weight, WSD: Water Saturation Deficit, SDW: Shoot Dry Weight, WUE: Water Use Efficiency, SI: Sprinkler Irrigation; SD_1: Surface Drip after using 80% of the FC; SD_2: Surface Drip after using 70% of the FC, SD_3: Surface Drip after using 60% of the FC, SD_4: Surface Drip after using 50% of the FC, SD_5: Surface Drip after using 40% of the FC, SD_6: Surface Drip after using 30% of the FC, H_1: non foliar application (control), H_2: gibberellic acid, H_3: epi-brassinolide, H_4: Acetylsalicylic acid; means within each column followed by the same letter are not significantly different ($P \leq 0.05$).

With increasing moisture content, leaf and stolon dry weight increased; however, the tuber dry matter decreased. This means that the more moisture in sprinkler irrigation compared to drip irrigation, the more it was used on the production of dry leaves and stolon, and therefore the tuber dry matter decreased. Ati et al, (2012) and Ghasemi-Sahebi et al. (2013) reported that increasing potato tuber yield in drip irrigation can be due to more uniformed distribution of water in the field, reduced soil nutrient losses, reduced water stress on the plant due to shortening the irrigation period, and reduced pathogenic factors in drip irrigation. Ayas, (2013) found that reducing irrigation water increased tuber dry matter about 75 percent of the potato tuber weight moisture. Therefore, this trait has been increased with decreasing moisture due to water loss in potato tubers. Yavuz et al (2012) reported that the higher potato yield obtained with less water usage in the drip irrigation. Khosravifar et al (2008) stated that Potato tuber yield improved with increasing irrigation periods. Bustan, et al (2004) reported that optimum potato irrigation led to higher leaf

Table 7
Correlations between all traits of potato in 2015

Variables	PH	LAI	LDW	WSD	N.S	N.T	SDW	TDM	TDW	WUE	RWC
(x_1)	1										
(x_2)	0.920**	1									
(x_3)	0.646**	0.573**	1								
(x_4)	0.731**	0.651**	0.980**	1							
(x_5)	0.881**	0.843**	0.553**	0.623**	1						
(x_6)	0.962**	0.925**	0.620**	0.696**	0.881**	1					
(x_7)	-0.647**	-0.624**	-0.553**	-0.599**	-0.660**	-0.705**	1				
(x_8)	0.840**	0.842**	0.240*	0.327*	0.788**	0.895**	-0.501**	1			
(x_9)	0.916**	0.844**	0.794**	0.857**	0.893**	0.912**	-0.756**	0.680**	1		
(x_{10})	-0.885**	-0.831**	-0.827**	-0.869**	-0.772**	-0.869**	0.722**	-0.618**	-0.903**	1	
(x_{11})	0.877**	0.820**	0.824**	0.865**	0.758**	0.860**	-0.726**	0.605**	0.894**	-0.997**	1

PH: Plant Height, LIA: Leaf Area Index, LDW: Leaf Dry Weight, WSD: Water Saturation Deficit, SDW: Shoot Dry Weight, WUE: Water Use Efficiency, RWC: Relative Water Content; * and ** show significance at P≤ 0.05 and P≤0.01, respectively.

Table 8
Correlations between all traits of potato in 2016

Variables	PH	LAI	LDW	WSD	N.S	N.T	SDW	TDM	TDW	WUE	RWC
(x_1)	1										
(x_2)	0.888**	1									
(x_3)	0.817**	0.767**	1								
(x_4)	0.857**	0.803**	0.986**	1							
(x_5)	0.699**	0.632**	0.466*	0.495**	1						
(x_6)	0.904**	0.818**	0.625**	0.679**	0.713**	1					
(x_7)	-0.686**	-0.649**	-0.649**	-0.670**	-0.458*	-0.675**	1				
(x_8)	0.585**	0.516**	0.081	0.149	0.600**	0.809**	-0.325*	1			
(x_9)	0.951**	0.841**	0.883**	0.914**	0.728**	0.851**	-0.753**	0.433*	1		
(x_{10})	-0.907**	-0.783**	-0.883**	-0.913**	-0.568**	-0.797**	0.664**	-0.363*	-0.939**	1	
(x_{11})	0.898**	0.769**	0.880**	0.910**	0.553**	0.793**	-0.668**	0.353*	0.936**	-0.997**	1

PH: Plant Height, LIA: Leaf Area Index, LDW: Leaf Dry Weight, WSD: Water Saturation Deficit, SDW: Shoot Dry Weight, WUE: Water Use Efficiency, RWC: Relative Water Content; * and ** show significance at P≤0.05 and P≤0.01 and 0.01, respectively

area index, increased stomatal conductance and, consequently, led to more photosynthesis and tuber weight. Lehrsch and Kincaid (2010) found that strike rain droplets derived of sprinkler irrigation causes aggregates deconstruction, soil surface compaction, pores deformation of soil surface layers, crust formation and delays in germination and tubers growth.

Pazoki et al, 2012 reported that gibberellic acid improved leaf area, leaf dry matter, shoot dry matter, and RWC. The use of gibberellic acid increased the production of potato tubers (Akbari et al., 2013; Shibairoet al., 2006)

Higher water use efficiency in drip irrigation, especially in dry and semi-dry regions, is a positive point. The amount of rainfall was very low in 2015 (0.06 mm) and no rainfall occurred in 2014 and 2016. Also, total volume of used water in drip irrigation was less than sprinkler irrigation. In drip irrigation, there is little moisture in rhizosphere zone permanently without losing a lot of moisture. As a result, drip irrigation is a suitable method for dry and semi-dry zones. Among different drip irrigation methods, daily and once per two-day drip irrigation were appropriate and useful for potato.

Use of hormones such as epibrassinolid and gibberellic acid along with drip irrigation increased physiological and morphological traits (except for WSD). It sounds that WSD is not affected by herbal hormones. Previous studies have been carried out to improve the physiological and morphological characteristics of potato using different irrigation methods along with various managements, such as selection of appropriate varieties (Cavero, et al., 2009; Yavuz et al., 2012), potassium fertilizer (El-Latif, et al., 2011), nitrogen fertilizer (El Mokh, et al., 2015), soil management (Olanya, et al. 2010), and soil amendments (Nedunchezhiyan, et al., 2013; Gibberson, et al., 2016).

Positive and significant correlations were seen between RWC and morphological characteristics (such as PH, LAI, LDW, N.S, N.T, TDM, and TDW). Enhancement of RWC improves morphological characteristics. RWC reflects metabolic activities in plant tissues. When plants are exposed to moisture stress, amount of RWC reduces and this leads to the decrease stomatal conductance, CO_2 absorption, and plant growth (Sadeghipour and Aghaei, 2012; Lawlor, 2002).

Enhancing pH and LAI caused increases in TDW and TDM because of improvement in stomatal aperture and more carbon dioxide absorption for photosynthesis, many nutrients are produced in leaves and transported toward tuber. There were negative and significant correlations between WUE and morphological characteristics (such as PH, LAI, LDW, NS, NT, TDM, and TDW). Moreover, a positive and significant correlation was observed between SDM and WUE (0.722) and, as a result, enhancement of SDM increased WUE. In fact, water use efficiency for producing SDM relative to potato yield (NT, TDM, and TDW) was more. This means that the plant has spent more water for producing SDM than tuber. As a result, correlation between most morphological characteristics of plant and WUE became negative. Because of this, TDW and TDM values were less in sprinkler irrigation compared to drip irrigation since sprinkler irrigation used more water to produce aerial organ (stolons and leaves) (Table 4). Also, improvement of plant height and leaf area index with increasing stomatal aperture and also amount of transpiration reduced WUE. Zrust and Geple, (1992) found that the number of leaves and leaf area index had positive correlation with yield and deficiency of water content reduced value of LAD, LAI, and the maximum total dry matter of the produced potato.

Conclusion

Potato is susceptible to water stress and irrigation has become a necessary component to product potato compared to the other crops. Losses and applied water volume were more in sprinkler irrigation relative to drip irrigation. As a result, WUE in sprinkler irrigation was less than that in drip irrigation. Because of the sensitivity of potatoes to soil water content, drip irrigation can be a good option for irrigation of these crops due to higher distribution uniformity and efficiency. Since the rainfall in the studied area is low, in order to improve the water use efficiency, other management strategies such as plant hormones along with drip irrigation must be used.

Epibrassinolid hormone increased the physiological and morphological characteristics of potato. Relationships between RWC and WUE application and morphological characteristics (such as PH, LAI, LDW, NS, NT, TDM, and TDW) were positive and negative, respectively.

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