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Original article

Evaluation of some physiological traits and yield of quinoa (*Chenopodium quinoa* Wild.) under different irrigation regimes

L. Moradi[1], E. Rohi[2], F. Hosseinpanahi[3*], A. Siosemardeh[4]

1. *Ph.D in crop physiology, Department of Agronomy and Plant Breeding, Faculty of Agriculture, University of Kurdistan, Iran*
2. *Ph.D in Agronomy, Agricultural Research Institute of Kurdistan, Sanandaj, Islamic Republic of Iran, Iran*
3. *Ph.D in Crop Physiology, Department of Agronomy and Plant Breeding, Faculty of Agriculture, University of Kurdistan, Iran*
4. *Ph.D in Agronomy, Department of Agronomy and Plant Breeding, Faculty of Agriculture, University of Kurdistan, Iran*

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Extended abstract

Introduction

Water deficit is one of the abiotic stresses that has many adverse effects on crop growth and yield. Understanding the mechanisms of the effect of drought stress on the plant plays an important role in managing different irrigation regimes to deal with adverse environmental conditions and improve crop yield management. Quinoa as a nutritious crop has attracted particular attention in recent years. In arid and semi-arid conditions, quinoa can be successfully cultivated in marginal soils, indicating that quinoa is an unpredictable plant. Today, agriculture needs to increase production per unit area, despite the limited water resources. To achieve the best results from the cultivation of each crop, careful and calculated management is required. Irrigation intervals are one of the most critical strategies that can improve water use efficiency.

Materials and methods

An experiment was conducted to investigate the effect of irrigation intervals and amounts on the quinoa's physiological traits and yield at the University of Kurdistan research farm, located in Dehgolan plain. The experiment was arranged in a split-plot scheme based on randomized complete blocks design with three replications. Four irrigation intervals (4, 8, 12, and 16 days) were considered the main factor, and four irrigation levels (100%, 75%, 50%, and 25% of plant water requirement) were considered secondary factors. Giza1 cultivar, which was obtained from the Seed and Plant Improvement Institute, was used for cultivation. Relative water content, membrane stability index, chlorophyll a, chlorophyll b, total chlorophyll, carotenoid, carotenoid/total chlorophyll ratio, biological yield, grain yield, and harvest index were measured.

Results and discussion

The relative water content of quinoa was decreased when the irrigation intervals increased. The highest decrease (13.87%) was observed in the irrigation interval once every 16 days compared to the control. The highest Relative water content was observed in the control treatment, while there were no significant differences between control and 75% water requirement treatments. The smallest (72.74%) and greatest (81.06%) membrane stability index were observed in 25% crop water requirement and

*Corresponding author: Farzad Hosseinpanahi; E-Mail: f.hosseinpanahi@agri.uok.ac.ir

control treatments. The highest chlorophyll a (10.68 mg.g^{-1} in dry weight), chlorophyll b (3.7 mg.g^{-1} in dry weight), and total chlorophyll (14.38 mg.g^{-1} in dry weight) content were observed in 100% crop water requirement with a 4-days interval, which was not significantly different from a 75% crop water requirement treatment with 4-days interval. The smallest (2.82 mg.g^{-1} in dry weight) and greatest (3.72 mg.g^{-1} in dry weight) carotenoid content were observed in 25% crop water requirement and control treatments. However, there were no significant differences between control and 75% crop water requirement treatment. Increasing the irrigation interval from 4 to 8 days reduced the biological yield and grain yield by 50.80% and 44.84%, respectively. The highest biological yield (4237 kg.ha^{-1}) and grain yield (1602.6 kg.ha^{-1}) were observed in the control treatment, which was not significantly different with 75% crop water requirement. The lowest (43.94%) and highest (50.78%) harvest index were obtained in the irrigation intervals of 4 and 16 days, respectively. Plants that were irrigated every 4 days at 25% of the plant water requirement had the highest water use efficiency (0.63 kg m^{-3}). Among irrigation amount treatments, the highest harvest index was observed in 25% water requirement. Increasing the irrigation intervals increased the grain protein content so that the 16-days irrigation interval treatment had the highest protein content, although it was not significantly different from the 12-day irrigation interval. The lowest grain protein content was observed in the control treatment, which was not significantly different with a 75% crop water requirement treatment. Drought stress reduced the relative leaf water content, membrane stability index, chlorophyll content, leaf carotenoids, biological yield, harvest index, and quinoa seed yield.

Conclusion

The results of the present study showed that despite the negative effects of drought stress on some physiological parameters, quinoa plant showed good relative resistance against water shortage, so that by providing just 25% of crop water requirements 812 kg.ha-1 could be achieved, which is considerable compared to many crops. Due to the fact that irrigation by 75% of plant water requirement did not reduce grain yield compared to control conditions, so this treatment can be used to irrigate the plant.

***Keywords*:** Antioxidant, Carotenoid, Chlorophyll, Compatible osmolytes

Table 1. Soil analysis of experimental site (0-60 cm).

Sand	Silt	Clay	OC	EC	pH	N	K	P
---------- % ----------				ds m^{-1}		%	---------- ppm ----------	
15.6	30	54.4	0.92	0.49	7.6	0.09	349.1	8

Table 2. Weather statistics during the experiment (2019).

	April	May	June	July	August
Minimum temperature (°C)	19.53	28.70	34.14	34.54	30.30
Maximum temperature (°C)	7.06	14.46	18.85	19.4	15.43
Precipitation (mm)	16.43	0.44	0	0.03	0
Minimum RH (%)	30.8	18.16	15.28	14.26	14.71
Maximum RH (%)	68.5	45.13	35.42	35.00	40.39

Table 3. Analysis of variance for relative water content (RWC), membrane stability index, chloropyll (chl) a, chl b, chl total (T), Carotenoid (Car.) and carotenoid/chl affected by irrigation interval and irrigation levels in quinoa.

S.O.V	d.f	RWC	MSI	Chl a	Chl b	Chl T	Car.	Car/ Chl T
Block	2	61.12^{ns}	6.97^{ns}	0.10^{ns}	0.025^{ns}	0.16^{ns}	0.11^{ns}	0.0004^{ns}
Irrigation interval (C)	3	440.2^{**}	427.87^{**}	17.04^{**}	0.0166^{**}	32.86^{**}	1.30^{**}	0.0040^{ns}
Error (a)	6	24.01	10.70	0.36	2.58	0.54	0.08	0.0004
Irrigation levels (I)	3	377.84^{**}	158.13^{**}	24.15^{**}	0.027^{**}	45.67^{**}	2.20^{**}	0.0031^{**}
I × C	9	6.85^{ns}	5.98^{ns}	0.48^{*}	3.40^{*}	0.89^{*}	0.16^{ns}	0.0005^{ns}
Error (b)	24	29.14	14.32	0.20	0.026	0.33	0.11	0.0006
CV (%)	-	*7.11*	*4.91*	*5.51*	*6.00*	*5.33*	*9.95*	*7.63*

ns, * and **: Not significant, significant at 5% and 1% probability levels, respectively

Table 4. Mean comparison effect of irrigation interval and irrigation levels on relative water content (RWC), membrane stability index (MSI), Carotenoid (car) and car/chl in quinoa.

Treatments	RWC	MSI	Car	Car/ Chl T
	%		mg g^{-1}DW	
Irrigation Interval (Day)				
4	81.49^{a}	82.81^{a}	3.64^{a}	0.287^{c}
8	79.10^{ab}	80.64^{a}	3.54^{a}	0.308^{b}
12	75.59^{bc}	75.32^{b}	3.23^{b}	0.328^{a}
16	67.62^{c}	69.44^{c}	2.92^{c}	0.321^{ab}
Irrigatin levels				
100%	81.98^{a}	81.06^{a}	3.72^{a}	0.293^{d}
75%	78.79^{a}	78.75^{a}	3.64^{a}	0.304^{c}
50%	73.85^{b}	$75.66b^{c}$	3.14^{b}	0.319^{b}
25%	69.19^{c}	72.74^{c}	2.82^{c}	0.330^{a}

Within each column (between two horizontal lines), mean followed by a different letter are significantly different at 5% level (Duncan).

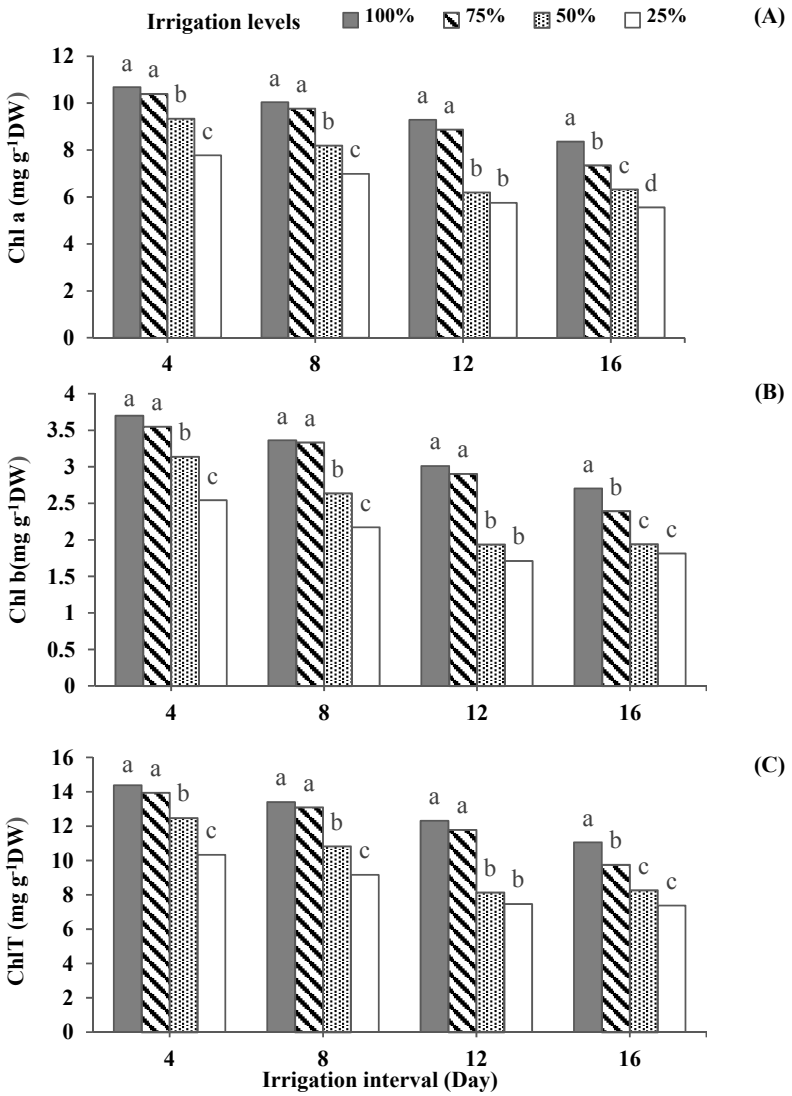

Fig. 1. Interaction slicing: Comparison of mean traits of chlorophyll a, chlorophyll b and total chlorophyll at each water requirement level. For each irrigation interval, columns with common letters according to Duncan test are not significantly different at the 5% probability level.

Table 5. Interaction slicing Mean of squares for different irrigation levels at any irrigation interval for chla, chlb and chlT.

Irrigation Interval	Chl a	Chl b	Chl T
4	10.03**	0.80**	5.13**
8	12.01**	1.00**	6.09**
12	18.35**	1.31**	9.87**
16	7.94**	0.51**	4.46**

ns, * and **: Not significant, significant at%5 and%1 probability levels, respectively

Table 6. Analysis of variance for biological yield (BY), yield, harvest index (HI), water use efficiency and grain protein content (GPC) affected by irrigation interval and irrigation levels in quinoa.

					WUE		
S.O.V	**df**	**BY**	**Yield**	**HI**	**BY**	**Yield**	**GPC**
Block	2	61574.7^{ns}	6031.9^{ns}	38.62^{**}	0.005^{ns}	0.0002^{ns}	0.81^{ns}
Irrigation interval (C)	3	10760483.4^{**}	1664527.4^{**}	95.75^{**}	0.761^{**}	0.1306^{**}	3.12^{*}
Error (a)	6	94408.3	24654.6	1.96	0.005	0.0017	0.40
Irrigation levels	3	18120668.1^{**}	2825005.0^{**}	155.13^{**}	0.189^{**}	0.0740^{**}	2.08^{*}
I × C	9	108465.1^{ns}	9418.8^{ns}	8.24^{ns}	0.054^{**}	0.0142^{**}	0.34^{ns}
Error (b)	24	151381.4	19023.1	5.73	0.007	0.0013	0.56
CV (%)		*12.04*	*9.41*	*5.09*	*11.48*	*10.28*	*4.63*

ns, * and **: Not significant, significant at%5 and%1 probability levels, respectively.

Table 7. Mean comparison effect of irrigation interval and irrigation levels on biological yield (BY), yield, harvest index (HI) and grain protein content (GPC) in quinoa.

Treatments	BY	Yield	HI	GPC
	----------Kg ha^{-1}----------		----------%----------	
Irrigation Interval (Day)				
4	4127.9^{a}	1790.7^{a}	43.94^{c}	15.59^{c}
8	3831.8^{a}	1729.0^{a}	46.46^{b}	15.75^{bc}
12	2939.6^{b}	1353.1^{b}	47.09^{b}	16.32^{ab}
16	2031.1^{c}	987.7^{c}	50.78^{a}	16.70^{a}
Irrigatin levels				
100%	4237.0^{a}	1866.5^{a}	44.57^{c}	15.59^{b}
75%	4123.7^{a}	1800.1^{a}	44.04^{c}	15.91^{ab}
50%	2967.1^{b}	1381.3^{b}	47.81^{b}	16.51^{a}
25%	1602.6^{c}	812.53^{c}	51.85^{a}	16.34^{a}

Within each column (between two horizontal lines), mean followed by a different letter are significantly different at 5% level (Duncan).

Table 8. Interaction slicing: Mean of squares for different irrigation levels at any irrigation interval for water use efficiency.

	WUE	
Irrigation Interval	**BY**	**Yield**
4	0.217^{**}	0.064^{**}
8	0.092^{**}	0.043^{**}
12	0.024^{*}	0.007^{**}
16	0.17^{ns}	0.003^{ns}

ns, * and **: Not significant, significant at %5 and %1 probability levels, respectively

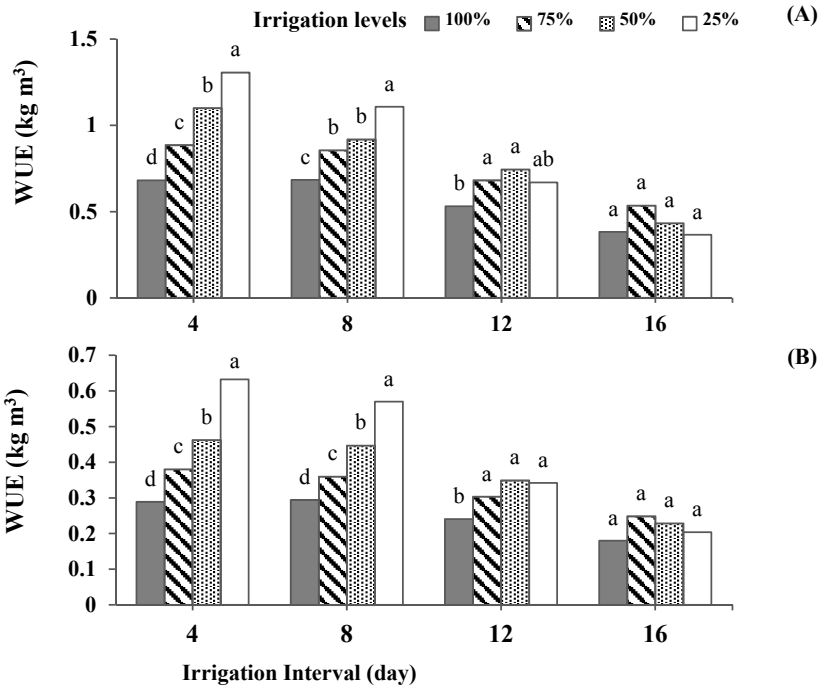

Fig. 2. Interaction slicing: Comparison of mean traits of (A) biological yield and (B) seed yield water use efficiencies at each water requirement level. For each irrigation interval, columns with common letters according to Duncan test are not significantly different at the 5% probability level.