The Effects of Irrigation Intervals on Yield, Yield Components and Water Use Efficiency of Roselle (*Hibiscus sabdariffa* L.)

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Research Paper

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The effects of irrigation intervals on yield, yield components and water use efficiency of Roselle (*Hibiscus sabdariffa* L.), was evaluated during the growing season of 2015 under field conditions at the Research Station of the Faculty of Agriculture, Iranshahr branch, Islamic Azad University, Iran. Irrigation and organic manure as organic fertilizer were employed within a split-plot design with three replications. Irrigation intervals were applied at three intervals of 7, 14 and 21 days, which were allocated to the main plots and five levels of fertilizer were allocated to the subplots. Results showed that irrigation intervals had significant effects on the number of capsules per plant, number of seeds per capsule, number of seeds per plant, seed weight per plant, seed yield, biological yield and harvest index (HI), but there was no significant effect on weight of 1000 seeds. The results showed that 14 day interval treatments and 21 day interval treatments with 708.56 and 621.75 kg/ha Sepal dry and 0.12 and 0.10 kg/m3 had the lowest and highest yield and water use efficiency, respectively. It seems that due to the lack of water in the area, treatment of 14 days irrigation interval registered highest Roselle Sepal production in Iranshahr, Southeastern of Iran.

Key words: Irrigation interval, *Hibiscus sabdariffa*, Water use efficiency.

INTRODUCTION

Medicinal plants are valuable resources in a wide range of natural resources that scientific identification, cultivation, development and proper utilization of them can be had very important role in community health, employment and non-petrol exports (Koocheki and Sabet Teimouri, 2011). Drought is one of the most important obstacles on the production of crops world-wide, particularly in arid and semi-arid regions (Yang *et al*., 2006). Proper practices of irrigation management and the cultivation of drought-resistant crops are some effective techniques for improving the utilization of the limited water resources in these regions.

Roselle (*Hibiscus sabdariffa* L.) belongs to the family of Malvaceae and is a drought-adapted crop (El-Boraie *et al.,* 2009). Roselle (*Hibiscus sabdariffa* var sabdariffa L.) locally called "Sour tea" is an important crop in tropical and sub-tropical regions. The economical part of the plant is the fleshy calyx (sepals) surrounding the fruit (capsules or boll). In Iran, fully developed fleshy calyx is peeled off from the fruit by hand and shade dried naturally which is considered as the consumer product (Javadzadeh, 2014). The plant, normally grown as an annual plant, 0.5 to 2 m in height. It has a bushy shape with a somewhat dense canopy of dark green leaves. The color of the calyx plays an important role in determining the quality of the crop. The crimson red color is the characteristic and most popular and desirable color of Roselle, while other shades and colors exist, including the white or greenish white color (El Naim and Ahmed, 2010). Roselle is an important cash crop in Southeastern Iran, where the largest area of is grown, especially Sistan and Baluchestan in Iranshahr and Dalgan areas. The crop is considered as a possible future crop, because of its natural production without using any chemical fertilizers and insecticides (Javadzadeh, 2014).

Irrigation can impact potential yield by affecting morphological and physiological traits Shubhra *et al*., (2004) found that plant height and the number of flowers per plant were considerably decreased under drought stress conditions. Chlorophyll level of plants is an important factor in maintaining their photosynthesis capacity (Jiang and Huang, 2001). It appears that the loss of chlorophyll under drought stress is brought about by the increase in production of oxygen radicals which causes peroxidation (De La Luz, 2004) and decomposition of these pigments (Vorasoot *et al.,* 2001). The stomata change by the decrease in stomata opening under drought stress is a plant reaction of which reduces CO_2 and water vapor flow and minimizes the loss of water by transpiration (Yordanov and Tsonev, 2000). Stomata conductance and chlorophyll content decreased as the moisture content of the soil was decreased in rape (Daneshmand *et al.,* 2008).

Although water is a limiting factor for plant production (Bannayan *et al.,* 2008), amild water stress has been shown to increase secondary metabolites in medicinal andaromatic plants (De-Abreu and Mazzafera, 2005). In fact, production of these metabolites has been considered as a defense mechanism in response to environmental stress (Gulen and Eris, 2004) including herbivores (Tucker and Maciarello, 1994).

The importance of Roselle (*Hibiscus sabdariffa* L.) in pharmaceuticals, food and cosmetics industries requires a strong need to conduct comprehensive studies on the cultivation and development of the plant. Previous studies have indicated that the construction of active ingredients in medicinal plants is influenced by genotype and environmental factors. Water, not only ecologically but also physiologically, is one of the important factors, that contributes to most of the internal processes in plants and almost all the metabolic activities in plant cells, including construction of active ingredients in medicinal plants (Norozpoor and Moghaddam, 2002; Riaz et al., 1996; Safikhani et al., 2007). Shortage of absorbed water by plants can cause a series of morphological, physiological and biochemical changes as following: reduced swelling and cell growth, thereby; reducing the leaf area and plant height, closure of stomata and photosynthesis limitation, increased soluble compounds for adjusting osmotic pressure, nutrients uptake reduction and ultimately decrease in the plant productivity. All of the former changes create different effects, depending on the plant’s growth phase, severity and duration of the stress (Lebaschi *et al.,* 2003). With an average rainfall of 240 mL, Iran is classified as one of the dry regions in the world. High rates of evapotranspiration, water resources constraints and other factors have made researchers to pay more attention to the studies on the effects of drought stress (Hassani *et al.,* 2005).The present study was designed to determine the effects of interval of irrigation on Roselle yield, yield components and water uses efficiency under the extremely arid climatic conditions prevailing in Iranshahr, Iran.

MATERIALS AND METHODS

The experiments were carried out at the Experimental Farm of the Faculty of Agriculture, Iranshahr Branch, Islamic Azad University, Iranshahr (Latitude: 27° 2’ N; Longitude: 60° 7’ E; Altitude; 591 m above sea level) during the growing season of 2014.The climate of this region is warm arid as assessed by using of Emberger method. The Embrothermic diagram shows that drought period extended for eight months of the year and wet season starts in November and continues until April (Figure 1).

The experimental soil was sandy loam in texture with 0.2% organic carbon, and the values of available N, P and K were 240.5, 34.6 and 160 kg/ha, respectively (Table 1). Iranshahr has a dry warm climate and rainfall mainly occurs between Novembers until April. Annual average rainfall is 167 mm. Table 2 shows rainfall and average monthly temperatures and relative humidity (RH) in Iranshahr in the growth season. Soil preparation operations were carried out in May.It was a split-plot experiment based on a Randomized Complete Block Design with three replications. The studied factors included irrigation intervals (at three levels of irrigation to 7, 14 and 21 days) as the main plot and fertilizer (at five levels) as the sub-plot. Disions of each sub-plot were 3 m × 6 m (18 m^2) and the distance between this plots was 0.5 m. Each plot contained four rows of 6 m length at a spacing between rows of 75 cm and row spacing was 0.5 m. Distances between main plots is 1.5 m and between the blocks was 2 m. The planting date was done at June 3^{rd} and planting was performed manually in the furrows with a depth of 0.5 cm. Thinning operations were performed in the four and eight leaf stages. In order to keep uniformity in emergence of seeds after planting, continuous irrigation was done and irrigation treatments began at the six leaf stage after full deployment of seedlings and continued until physiological maturity. Before men planting, the field was fertilized with 46 kg P_2O_5/ha in the form of triple super phosphate (TSP) and 150 kg ha^{-1} potassium sulfate at planting time. Urea was applied as a top dressing in two phases concurrent with irrigation; first during the last week of July and second during the last week of September, the irrigation system adopted in these experiments was surface irrigation. During the crop growing seasons, plants were received 7-21 irrigations including planting irrigation. Table 3 shows irrigation regimes which included three treatments and the number of irrigations and total amount of applied water during the season. Furthermore, during the different growth stages of the crop, all the necessary

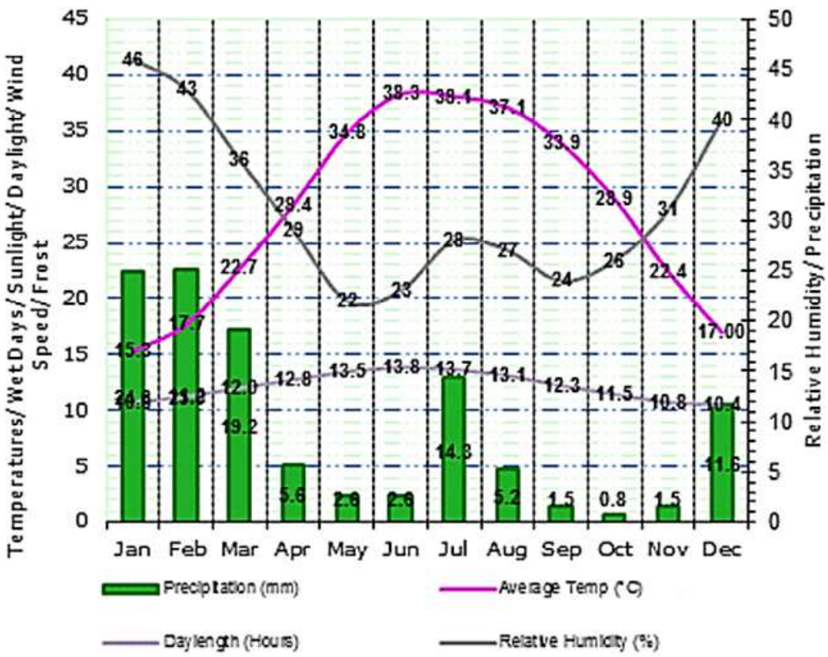

Figure 1. The Embrothermic curve of Iranshahr station related to 2013-2014.

Table 1. Chemical and physical properties of soil samples from experimental plotsin 2014-2015.

Texture	Total N (%)	Organic carbon (%)	Available K (ppm)	Available P (ppm)	EC (mmohs.cm-1)	pH
Sandy-loam	0.01	0.2	60	2.7	1.62	8.35

AV. P, ppm = Available phosphor O.C. = Organic Carbon, O.M. = Organic matter,
F.C. = Field Capacity, P.W.P. = Permanent wilting point. Av. Mois. = Available moisture.

Table 2. Rainfall, average monthly temperatures and relative humidity (RH) in Iranshahr in the growth season in 2015.

Month	Temperature (°C)			Rainfall (mm/month)	RH (%)
	Maximum	Minimum	Average		
May	41	25.6	33.2	0	33.33%
June	45	30	37.7	0	20.82%
July	32	38.9	45	0	38.67%
August	27.1	35.1	43.2	0	32.67%
September	27.4	32.8	40.2	0	28.51%
October	21.8	38.2	36.3	3	30.33%
November	11.6	19.9	28.2	4.3	25.42%

agronomic practices were carried out accordingly. Flood system, irrigation, which is the normal irrigation system used by farmers in Iranshahr area was performed in this study. Plants were irrigated every 7, 14 and 21 days after sowing with amounts of water 18900, 13250, and 7600 m^3/ha, respectively (Table 3).The spacing between the seeds was 50 cm in rows and the row spacing was 75 cm. Each sub-plot consisted of five rows (3 m long). Since the growth period coincided with the early cold weather (November) and sepals had stunted growth, whole reproductive systems of the plants were harvested and were regarded as flower yield. When the plants were yellow, but capsule has not cleared yet, harvesting operation was performed in November 15th. At first, ten plants per plot were randomly selected for measurement of yield components. After eliminating two side rows and 0.5 m from both sides of the plots as the marginal effect, 10 plants were randomly harvested from each plot, to determine the yield level and the remaining area was harvested.Finally, plant growth variables, including fleshy

Table 3. Summary of experimental treatments used in the field.

Treatments	Water in plot (liter per irrigation)	Irrigation interval (Days)	Irrigation number	Total used water in plots (liter per total period)
I_1	1080	7	21	22680
I_2	1136	14	10	15900
I_3	1303	21	7	9120

calyx (sepals), grain yield, shootdry matter, weight of thousand seeds (WTS), plant height (cm), stem diameter (mm), branches number, bolls number in the plant and boll weight were measured. In addition, irrigation management variables, including water used volume, irrigation intervals, and water use efficiency was calculated.

Water use efficiency was calculated as grain yield and fleshy calyx (sepals) divided by total used water during the growth season. Mean irrigation intervals were measured by averaging irrigation intervals in different growth stages. The data were statistically analyzed by software MSTAT-C and SAS (2001) and the means were compared with Duncan Multiple Range Test at 5% probability level.

RESULTS AND DISCUSSION

Plant height and stem diameter

Table 4 reveals that the intervals of irrigation showed a significant effect on plant height. The maximum height of the irrigation 7 days (119 cm) and the lowest irrigation of 21 days (108 cm) was obtained, which were significantly different at the 5% level of significance. Plant height was significantly reduced under the intervals of irrigation (Table 4).

Our results were generally in line with Anupama *et al.,* (2005) on chrysanthemum plant, Gaballah *et al.,* (2007) on *Helianthus annuus*, Yousef *et al.,* (2008) on *Majorana hortensis* L., Hojati *et al.,* (2011) on *Carthamus tinctorius* L., Khalil *et al.,* (2012) on *Capsicum annuum* L. and Bahreininejad *et al.,* (2013) on *Thymus daenensis*. The reduction in plant height under water stress were perhaps due to the decline in the cell enlargement and more resulting from reduced turgor pressure (Shao *et al.,* 2008).

Plant height and stem diameter were significantly decreased as irrigation intervals increased with no significant differences obtained between 7 and 14 days. Higher plant height was reported at 7 and 14 days compared with 21 days. This trend was also reported in stem diameter, but the negative effects of long irrigation intervals have been occurred in 21 days interval.

This may indicate the role of water available in cell elongation. Number of branchs/plant showed a similar trend as reported for plant height (Table 4).

Number of Seeds per boll

The effect of irrigation intervals on the seeds number per boll was significant ($p < 0.01$) (Table 4).The obtained results from the mean comparison (Table 5) shows that maximum seeds number per capsule was observed in 14 days irrigation intervals representing a significant difference with 7, 21 days irrigation intervals. Hence, the highest and lowest seeds number per capsule were observed at 14 days irrigation intervals with 21 days irrigation intervals, respectively (Table 4). Bannayan *et al.,* (2008) reported that an increase in the seeds in *Nigella sativa* and reduction in irrigation intervals coincide. In many crop plants, the occurrence of water stress during the flowering period is critical and in this case, the flowers number that turns into seeds become significantly reduced (Kazempour and Tagbakhsh, 2002). The irrigation interval (14 days) produced more seeds per boll than any of the other treatments and the irrigation treatment (7 days) gave the next highest (Table 4). Similar results were reported by El-Saidi *et al.,* (1992); Barszczak, *et al.,* (1993) and Abbas *et al.,* (1999) regarding Canola (*Brassica napus* L.). Different irrigation treatments showed significant effect on seed yield of the Roselle crop (Table 4).

Number of capsule per plant

The obtained results from variance analysis (Table 4) indicated that the effect of irrigation intervals on the capsules number per plant was significant ($p < 0.01$). Maximum number of capsules per plant was observed in 14 days irrigation intervals showing a significant difference with 21 days irrigation intervals (Table 3). Considering the fact that Roselle (*Hibiscus sabdariffa* L.) is a plant with indeterminate flowers and unlimited growth, in which the flower and fruit form at the Non-end of each branch, the number of bolls per plant follows flowering branches number. It seems that under optimum irrigation conditions, it is possible for the plant to create a close relationship between the capsules number per plant and genetic potential. When the plant is provided with optimum irrigation, it will experience greater vegetative growth, produce more branches and, thus; increase the capsules number (Bannayan *et al.,* 2008).Significant differences in the mean number of bolls per plant were observed among different irrigation intervals.The average

Table 4. Analysis of variance (mean squares) of Roselle irrigation intervals on yield and yield components.

Source of variation (Sov)	Degree of freedom (df)	Mean of squares (MS)						
		Plant height	Stem diameter	Number branches	Number of bolls/plant	Bolls weight	Sepal yield/ (Kg/ha)	Water use efficiency
Replication	2	142.33	7.70	1.09	38.69 ns	0.32	5980/85 ns	0.0001 ns
A (Irrigation)	2	508.43 *	24.92 *	5.28 **	129.03 **	0.43 ns	28359/47 *	0.0008 *
Main Error	4	240.65	1.85	0.244	15.03 **	0.002 ns	2046/82	0.0001
B (fertilizer)	4	1735.47	79.15 **	15.33 **	572.49 **	0.51 ns	94473.14 **	0.0025*
A × B	8	5.21 ns	0.727	0.13*	18.37**	0.37 ns	2830.79 ns	0.0007ns
Sub Error	24	7.57	0.124	0.01	4.58 ns	0.001	414.31	0.0003
CV (%)		2.03	1.33	1.59	4.19	11.45	4.24	5.95

**, * and ns are significant at 1% and 5% probability levels and non-significant, respectively.

Table 5. Effect of irrigation intervals on Yield and yield components Roselle.

Treatments	Plant height (cm)	Stem diameter (cm)	Branches number	Bolls number/ plant	Sepals weight per boll (g)	Sepal yield/plant (g)	Sepal yield (kg/ha)	Water use efficiency (Kg m^{-3})
7 days	119.80a	25.15b	8.48b	58.50 b	0.83b	49.35b	669.59 b	0.10 b
14 days	114.36b	26a	8.84a	59.96 a	0.86a	52.23a	708.56 a	0.15 a
21 days	108.17c	23.47c	7.50c	54.31 b	0.84b	45.83c	621.75 c	0.12 b

*Means in each column and each treatment followed by similar letters are not significantly different at the 5% probably level.

number of bolls per plant decreased with increasing irrigation intervals. The 14 and 7 day interval treatments produced a significantly higher number of bolls than any of the other treatments (Table 4). These results are consistent with those reported by Wright *et al.,* (1988); Al Jaloud, *et al.,* (1996) and Leilah *et al.,* (2002). The higher number of bolls/plants under shorter intervals could be attributed to the higher number of flowers/plant.

Number of seeds per plant

The obtained results from variance analysis (Table 4) indicated that the effect of irrigation intervals on the seeds number per plant was significant ($p < 0.05$). Akbarinia *et al.,* (2003) reported that with the increasing irrigation intervals, the seeds number in *Nigella sativa* increased as well. It sounds like that the presence of moisture increased capsules number per plant, which in turn, increases the seeds number per plant. It appears that an increase in the seeds number under lower drought stresses might lead to more and larger capsules, as well as a better growth of plants (Akbarinia *et al.,* 2003).

Thousand seed weight

The obtained results from variance analysis (Table 4) indicated that the effect of irrigation intervals on the seed weight were not significant. Norozpoor and Moghaddam, 2002 reported that 1000 seed weight per capsule / plant was not affected by irrigation intervals. Overall, 1000 seed weight is considered a factor which is mostly under genetic control, has high heritability and is less affected by environmental factors. Means seed weights were ranged from 33.63 to 41.52 g. Marked differences were found in 1000-seed weight among the irrigation intervals, except 7 and 14 day intervals. Both 7 and 14 day intervals had significantly higher means seed weights than any of the other treatments, but means seed weight did not differ significantly between them (Table 5). These results support the findings of Omobuwajo *et al.,* (2000), who reported an average 1000-seed weight of 34.9 – 36.30 g. Differences in means seed weight may be much related to a shorter period between a thesis and maturity. At this time, the supply of assimilates to the boll (seed) plays a crucial role in the development of the seed, and plants supplied with more nutrients and water are probably at an advantage over those supplied with less (Taylor *et al.,* 1991; Gary, 2001) which seems to be occurred under shorter intervals of the present study.

Seed weight per plant

The effect of irrigation intervals on the seed weight per plant was significant ($p < 0.01$) (Table 4). The obtained results from of mean comparison (Table 5) indicated that with increasing of irrigation intervals, the seed weights per plant were reduced. The increase in seeds (or grains) weight in the absence of sufficient water in plant are associated with duration and rate of grain filling; and the longer the period, the faster the rate is, the highest seeds weight is gained.

Sepals yield and biological yield

In the present study, sepal dry yield of Roselle (*Hibiscus sabdariffa* L.) has increased in response to shortening irrigation intervals with maximum yields (708.56 kg ha^{-1}) being obtained with 14 days irrigation intervals. However, there were no significant differences between 7 and 21 day irrigation intervals. This indicates that with shortening irrigation intervals, the increase in sepal yield was not proportional. This increase was 6% between 14 and 7 days and it was just 14% between 14 and 21 days.

The effect of irrigation intervals on the seeds and biological yield was significant ($p < 0.01$) (Table 4). The obtained results from mean comparison (Table 5) indicated that with increasing of irrigation intervals, the seeds yield increased. These results are consistent with those reported by Koutroubas *et al.,* (2002). The increase in seeds yield can be attributed to better vegetative growth, canopy development and, therefore, better use of solar radiation and higher photosynthesis in optimum irrigation conditions (Filippo *et al.,* 2002). Considering the number of capsules per plant, number of seeds per capsule and seeds weight, the three of which are considered as the yield components of Roselle (*Hibiscus sabdariffa* L.). Perhaps it can be stated that the increase in grains yield in optimum irrigation conditions is largely due to its effect on the number of capsules per plant directly and the increase in number of seeds per plant indirectly (Akbarinia *et al.,* 2003; Iiriti *et al.,* 2009).

Harvest index (HI)

The obtained results from variance analysis (Table indicated that the effect of irrigation intervals on HI became significant ($p < 0.01$). The mean comparison (Table 5) suggests that there are significant differences between 7 and 14 days irrigation intervals. It sounds like that the reduced HI at 21 and 7 days irrigation intervals treatments has resulted in a decrease in vegetative growth and competition of chlorophyll organs with reproductive organs, which therefore resulted in less assimilates that eventually will be allocated to the seeds. After pollination, the materials are transmitted to seeds and the water plays an important role in transmission process of materials. Therefore, it seems that due to lack of water, in the 21 days irrigation interval and control treatments, transmission process of water decreased which consequently resulting in the reduced HI.

Water use efficiency

Water use efficiency is an important criterion to determine efficient water use. The water use efficiency (WUE) was calculated by dividing the sepal yield with total used water as evapotranspiration, throughout the growing season, according to crop water requirement given. Mean values of WUE for sepals Roselle were 0.112, 0.118, and 0.103 kg**/**ha sepal obtained from I1, I2, and I3 irrigation treatments, respectively (Table 5). Also, results shows that though WUE was slightly higher in the I2 than in the I1 treatment, the difference was not significant. This suggests that Roselle soil used, water more efficiently at a 14-day irrigation interval than either the I1 (7-day irrigation interval) or the I3 (21-day irrigation interval) treatments. This indicates that reasonable Roselle production could be obtained when irrigation is carried out at a 14-day interval for the summer crop season in Iranshahr. Water use efficiency (WUE) for the evaluated irrigation treatments (Table 4) recognizes the ratio between sepal yield and volume of irrigation water. It reveals that irrigation Roselle plants every 14 days associated with the highest values of WUE over both treatments of study. So, it can be reported that with absent of significant differences in sepals yield between 7 and 21 days, irrigation Roselle every 14 days was the most benefit irrigation treatment under the conditions of this study.

CONCLUSION

The irrigation intervals were significant in their effect on plant height, dry matter and seeds yield, 100-seeds weigh and water use efficiency. Among the various irrigation treatments, 3 treatments (21-day irrigation interval) caused a significant reduction in all the reported plant growth parameters. The study indicated that irrigation at 14-day irrigation interval is optimum for reasonable Roselle production in Iranshahr. In general, it can be concluded that irrigation Roselle plants at the regular interval of 14 days under the environmental condition of Iranshahr region.

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