



Impact of water availability and fertilization management on saffron (*Crocus sativus* L.) biomass allocation

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ABSTRACT

Purpose: The aim of this study was to investigate the effect of fertilizer type and irrigation scheduling on biomass partitioning in saffron. **Research Method:** The experimental factors were saffron fertilization (no-fertilizer, cow manure and NPK chemical fertilizer) and irrigation regimes (FI=7200 and DI=3600 m³ ha⁻¹) which were tested during 2015-16 growing season, using a factorial layout. **Findings:** The weights of roots and leaves had an increasing trend up to 72 and 114 days after first autumnal irrigation (DAFAI), respectively, and then were decreased. Corm production started from 51 DAFAI and its maximum was obtained at DI and chemical or organic fertilizer application. In all combined treatments corm production (maximum rate between 114 and 157 DAFAI) was prior to corm filling (started from 135 DAFAI) and both mentioned indices were higher in DI. The weight of replacement corms per clone in plants that were treated by cow manure and received 7200 m³ ha⁻¹ water, was higher (~10%) than all other treatments. Corm growth rate increased from 50 DAFAI and the maximum value (0.32 and 0.34 g day⁻¹ plant⁻¹ in 56 and 78 DAFAI, respectively) obtained at combined treatment of FI × cow manure. **Research limitations:** Access to similar scientific references on the topic of research was a limitation. **Originality/value:** This study was the first research which specifically deals with the allocation of photo-assimilates in saffron and based on its findings, application of 3600 m³ ha⁻¹ water plus cow manure is an appropriate strategy in saffron cultivation during first growing season.

INTRODUCTION

Saffron (*Crocus sativus* L.) a member of Iridaceae family, botanically is a geophyte herbaceous plant which is usually cultivated as a perennial crop in many parts of the world like Iran. This plant is considered as a spicy and medicinal plant and its stigma and sepals can be used in perfumery and food industries (Fallahi et al., 2014). Saffron occupies about 87,000 ha area with 280 tons annual dry stigma production in Iran, which represents about 90% of the world saffron production (Ahmadi et al., 2015). Saffron oil has more than 150 volatile and aromatic compounds mainly includes terpenes, terpene alcohols, and esters. Three main components of saffron stigma are picrocrocin (agent of a bitter taste), safranal (responsible for odor) and crocin (carotenoid pigment which is an agent of red color) (Ahmed et al., 2016).

In saffron, during each growth season (mid-fall to mid-spring) replacement corms develop on the buds of the mother corm and the photosynthetic activity of the leaves and mother corm reservoir contributes to the formation of these new corms (Fallahi et al., 2016). In semi-arid areas like Iran, at the mid-spring (after leaf senescence), real dormancy of corms begins and continues nearly up to July 10. After that, the pseudo-dormancy starts which during this stage the transition to reproductive phase occurs (from mid-July to early-August initial leaf genesis starts and from 1 to 15 August the flower initiation occurs and continues up to September). In the fall, with temperature reduction (~15-17 °C) and after water availability, the flowering phase occurs and takes about 20 days. Usually, at the end of the flowering stage, the leaves appear and vegetative growth starts. Concurrent with the flowering and leaf emergence, the production and growth of the fibrous root take place. From late-November to mid-December, replacement corms start to grow from the buds on the mother corm. These corms can be formed at lower rates during the late winter and even early spring. In late winter root system becomes weak and finally, at the end of May the leaves are withered and another period of real corm dormancy starts (Behdani et al., 2016; Koocheki et al. 2009; Renau-Morata et al. 2012).

Identification of source-sink relations is one of the most important factors for appropriate agronomic management in plants. In saffron, mother corms and leaves are the major sources, while roots, replacement corms, and early leaves are the main sinks. Moreover, remobilization of reserved nutrients in leaves towards replacement corms occurs at the ends of vegetative growth period (Behdani et al., 2016). In general, plant performance depends on its ability in mineral uptake, carbon fixation and allocation of photo-assimilates over the plant organs as well as its tolerance to environmental stresses. In each plant, the pattern of biomass allocation determines investment in photosynthetic, reproductive and nutrient absorbing organs. Given this, shifts in biomass partitioning can exert a significant effect on the plant ability for resources utilization. In addition, the method plants respond to variations in water and nutrient availability strongly influences their ability to grow and compete under field condition (Zhang et al., 2015).

It has been reported that source-sink relations and the biomass partitioning in saffron can be affected by many environmental and agronomic factors such as temperature, planting date, corm size, corm density, rainfall and fertilization (Behdani et al., 2016). This is similar to findings of Gholami et al. (2017), who reported that biomass partitioning in saffron has a near relation with good water and nutrient availability. Also, Renau-Morata et al. (2012) studied the source-sink relations in saffron and reported that when the roots and leaves reach to their maximum size, the growth of replacement corms was initiated and their development mostly relied on photosynthesis. Biomass partitioning in other crops has also been considered. In a study on soybean, it was concluded that urea + manure application combined with one

irrigation at pod formation stage was caused to better root growth and greater biomass partitioning towards pods (Bandyopadhyay et al., 2013). In another study on rice, shoot to root ratio in mycorrhizal inoculated plants enhanced with increasing fertilization by urea, phosphorous and potassium. In addition, inoculation increased panicle to shoot ratio, panicle N to shoot N ratio and panicle P to shoot P ratios, in plants were grown at a low level of chemical fertilizers (Zhang et al., 2015). However, biomass partitioning in saffron as a bulbous sub-hysteranthous plant (Juan et al., 2009), is different from common agronomic plants. This is mainly because saffron flowering occurs before its vegetative growth that is a special phenomenon which can be seen in few plants (Behdani & Fallahi, 2015).

So far the effects of chemical (Heidari et al. 2014; Rezvani-Moghaddam et al., 2014) and organic fertilizers (Koocheki et al., 2016; Yarami & Sepaskhah, 2015) as well as irrigation management (Azizi-Zohan et al., 2009; Juan et al., 2009; Sepaskhah & Kamgar-Haghighi, 2009) have been studied on saffron growth and flowering, and it has been concluded that saffron responds positively to appropriate water and nutrients availability. However, the influence of these factors on biomass partitioning among different organs of the plant has not been fully investigated in previous studies. Therefore, this experiment aimed to evaluate the impact of water and nutrient availability on saffron biomass partitioning pattern during its growth cycle. Identification of biomass partitioning pattern will help us to find the critical stages of plant growth regarding nutrition and irrigation management in accordance with these stages.

MATERIALS AND METHODS

Aim and experimental site

In order to evaluate the effects of water and nutrient availability on saffron biomass partitioning, a field experiment was conducted at the research field of Sarayan Faculty of Agriculture, University of Birjand, Iran, during 2015-16. Sarayan (33 °N, 58 °E and 1450 m elevation) is characterized by a semi-arid climate with average annual precipitation of 110 mm and mean annual temperature of 17 °C. In this county, nearly 90% of rainfall takes place during saffron vegetative growth.

A factorial experiment based on a randomized complete block design with three replications was conducted. Experimental factors included irrigation management (application of 7200 and 3600 m³ ha⁻¹ water in intervals of 14 and 28 days, respectively) and fertilizer type (no-fertilizer, cow manure, and chemical fertilizer). In the organic fertilized treatment, the equivalent to 30-ton ha⁻¹ rotten cow manure and in the chemical nutritional treatment, respectively, 220, 150 and 100 kg ha⁻¹ urea, super-phosphate and potassium sulfate were used as pre-planting. Therefore, the net N, P and K from chemical fertilizers was 101, 70 and 52 kg ha⁻¹, respectively. The amounts of N, P, K in cow manure has been shown in Table 1. Cow manure was mixed manually with the soil and chemical fertilizers were used below planting rows.

Table 1. Properties of cow manure and experimental site with respect to soil

	EC [†] (dS. m ⁻¹)	pH	O.C [‡] (%)	N total (%)	P ava (ppm)	K ava (ppm)	Sand (%)	Silt (%)	Clay (%)	Texture
Soil	2.27	8.49	0.13	0.016	2.07	194.9	48.5	22.5	29	Loam
Cow manure	6.42	7.3	44	1.10	715	4121	-	-	-	-

[†]EC= electrical conductivity; [‡]O.C= organic carbon.

Before planting a mixed sample from the soil of experimental plots was prepared. The main physical and chemical properties of soil are presented in Table 1. Corm planting was

done on October 11, 2015, in rows with 20 cm distance. Corms spacing in each row was 10 cm and planting depth was 15 cm. In each plot (2 m²), 100 mother corms with an average weight of 7-8 g were planted. First irrigation of all plots was done in October 21 and the second one at the end of flowering phase in November 20. Then, irrigation treatments were applied separately in each plot, as in 14 and 28 days irrigation intervals, 12 and 6 times irrigation was done respectively, until the end of saffron growth cycle early in May, 2016. For proper implementation of irrigation, the around of all 18 experimental plots borders were created with soil to a height of 25 cm.

For evaluation of biomass partitioning, plant sampling was performed 9 times at intervals of 21 days during the growth cycle of saffron. First and final sampling dates were on November 22 and May 9, respectively. Three plants (including batches of corms, roots, and leaves) were removed at each sampling date and then growth traits including mother corm dry weight, mean and total dry weights of daughter corms per clone, number of replacement corms, scale weight, root dry weight and leaf dry weight were measured. In addition, replacement corms growth rate (g dry matter per clone per day) was determined using equation 1. In which, RCWSS, RCWFS, and NDBTS are replacement corms weight in the second sampling date, replacement corms weight in the first sampling date and the number of days between two sampling, respectively (Fallahi & Mahmoudi, 2018b).

$$\text{Replacement corms growth rate} = \frac{\text{RCWSS} - \text{RCWFS}}{\text{NDBTS}} \quad (1)$$

The time needed to replacement corms to reach from 25 to 90% of their final weight was considered as the active period of corm filling. Accordingly, the beginning, the end, and duration of this period was determined in each treatment. The amount of remobilization of dry matter from leaves to replacement corms (g per clone) and leaves efficiency in remobilization of dry matter (%) was calculated using equations 2 and 3 (Fallahi and Mahmoudi, 2018b).

$$\text{Remobilization of dry matter} = \text{MLWDVGC} - \text{LWEGC} \quad (2)$$

$$\text{Leaves efficiency in remobilization} = \frac{\text{ARDM}}{\text{MLWDVGC}} \times 100 \quad (3)$$

Where, MLWDVGC= maximum leaves weight during the vegetative growth cycle, LWEGC= leaf weight at the end of growth cycle (sampling 8 on 19 April) and ARDM= amount of remobilization of dry matter.

Statistical analysis

Statistical analysis of experimental data was made using analysis of variance (ANOVA) procedure in SAS 9.2 statistical program (SAS Institute Inc., NC, USA). The means were compared with Fisher protected LSD at 5% level.

RESULTS AND DISCUSSION

Root weight

There was no significant difference between nutritional and water treatments in terms of root weight of saffron in all nine sampling dates. It has been shown that saffron is resistant to drought stress, however, severe water shortage under rainfed condition was pointed out to cause a reduction in root number and weight (Sabet-Teimouri et al., 2010). In another study on saffron, water stress resulted to a decrease in the photosynthetic rate, but water provided to the leaves from the corms and roots maintained a still high photosynthetic activity even at

severe drought stress (Renau-Morata et al., 2012). In the current study, the root weight in no-fertilizer application treatment at both irrigation levels was higher (between 38-171%) especially during the last 40 days of growing season (Fig. 1). This observation may be due to the fact that plants living in soils with low fertility, typically partition a considerable part of their biomass to belowground structures (Cambui et al., 2011).

In all combined treatments, root weight increased up to January 15 (90 days after first irrigation) and then continued with a decreasing trend (Fig. 1). In another study on saffron, it was shown that the maximum root weight obtained in the middle of January and then reduced (Renau-Morata et al., 2012). The amount of this index in the two last months of growth season was very little and finally reached to zero in the middle of April (Fig. 1). Accordingly, the foliar nutrient application is considered as an appropriate strategy for better replacement corms growth in the last vegetative growth stage (Mollafilabi, 2014). In a similar study on saffron, it was reported that root weight increased at the beginning of the growing season (120 days after growth) and then followed by a declining trend up to the end of vegetative growth phase in mid-spring (Behdani et al., 2016).

Leaf dry weight

The amounts of leaves weight in all sampling dates in cow and chemical fertilizers treatments was some higher than control treatment (Fig. 2). These results are due to the nutrients providing (Table 1) and the relative improvement of soil physical qualities by cow manure during first growth cycle (Behdani & Fallahi, 2015). Although it seems that full effects of organic manure on soil properties will appear in coming growth cycles. In addition, cow manure partially decreases the soil density during the first growth cycle of saffron which leads to lower mechanical resistance against the growth and proliferation of new corms, as well as leaves emergence (Rezvani Moghaddam et al., 2014). Leaves weight for 28 days irrigation intervals was about 10% more than 14 day's irrigation intervals. In a similar study on saffron, a linear decrease in the photosynthetic rate was observed with decreasing soil water availability (Fig. 2). However, there was no severe decrease in photosynthetic rate under very low soil water potential (Renau-Morata et al., 2012). They stated that providing water from the corms and roots to the leaves could alleviate the effects of water stress on the leaves during a particular growth period.

In all combined treatments, leaves weight was reached to its maximum value in early February (114 days after first irrigation) and then was decreased. Gholami et al. (2017) concluded that leaf length of saffron increased up to 125 days after emergence and then remained stable. At the peak of leaves weight the average weight of replacement corms was about 1g, while, with the beginning of leaves weight loss, the weight of replacement corms increased rapidly and finally reached to about 6 g (Fig. 6). This phenomenon shows that in saffron probably a remobilization of photo-assimilates takes place, in which biomass is translocated from leaves to replacement corms at the end of growth cycle (Behdani & Fallahi, 2015). Therefore, replacement corms filling is dependent on current photosynthesis as well as photo-assimilates remobilization. This observation is very similar to that reported by Behdani et al. (2016), and to some extent with results of Renau-Morata et al. (2012) which concluded that in plants produced from small and medium corms, leaves weight decreased from March, although this reduction was very lower than those was observed in our study (Fig. 2). Gholami et al. (2017) stated that there is a two-way relationship between the corms and leaves of saffron, so that, both organs act as a reservoir in a part of the growth cycle and as a sink in the other part.

Renau-Morata et al. (2012) stated that leaves are the main source of organic matter production in saffron, as the subsequent growth of the replacement corms (main sinks) is

primarily (~90%) supported by their photosynthesis activity. Their studies showed that replacement corms growth is not limited to providing of photoassimilates by the leaves; instead, the growth is limited by sink capacity since biomass enhancement was limited before total leaf senescence. However, we think that saffron is a source- limited crop, because replacement corms had a rapid weight increasing in their last growth phase (Fig. 6), and unlike results of Renau-Morata et al. (2012), leaves weight reduced rapidly in this stage (Fig. 2). This biomass reallocation shows that the capacity of replacement corms wasn't limited. Considering to replacements corms weight in Renau-Morata et al. (2012) study which was between 10-55 g and in our study that was about 6 g (Fig. 6), it seems that sink-limitation occurs when saffron corms become very large. Production of larger corms in their study at Valencia may be due to better soil and climatic conditions for saffron growth.

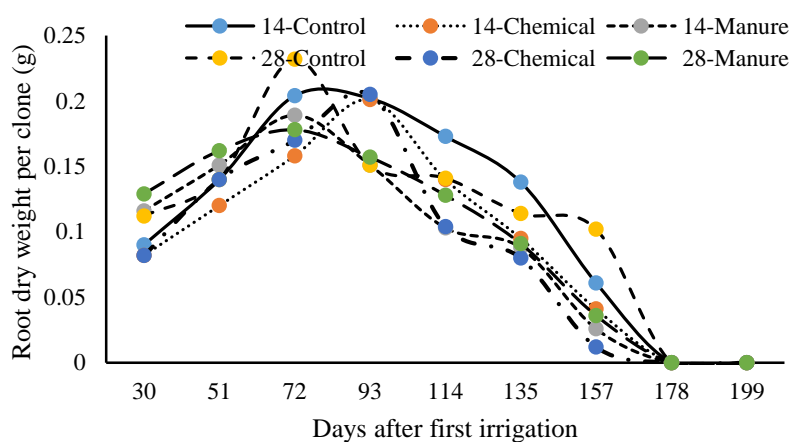


Fig 1. Root dry weight trend in saffron during growth cycle affected by irrigation and fertilizer management (First irrigation was done in October 21; 14= application of 7200 m³ ha⁻¹ water in intervals of 14 days, 28= application of 3600 m³ ha⁻¹ water in intervals of 28 days, Control= no-fertilization, Chemical= chemical fertilizer and Manure= cow manure). There is no significant different between treatments in all sampling dates, therefore, the letters describing groups of means are similar and missing.

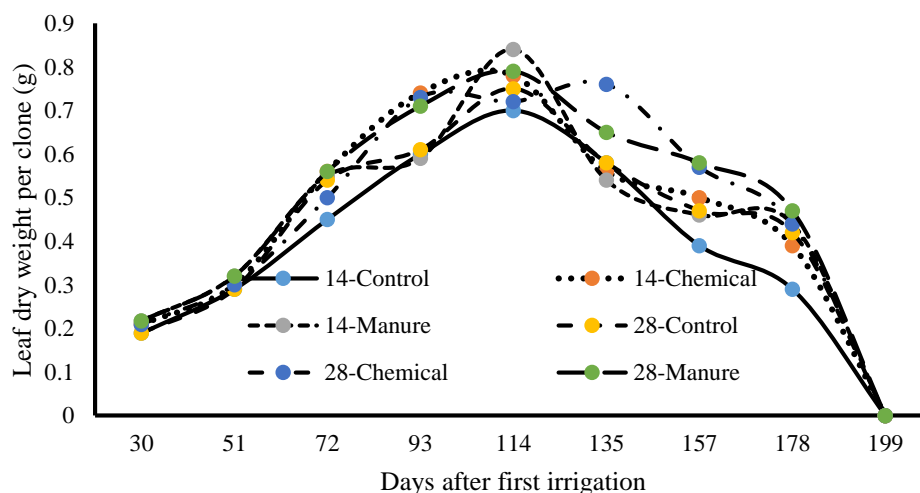


Fig 2. Effects of irrigation and fertilizer management on leaf dry weight trend in saffron during its growth cycle (First irrigation was done on October 21). Explanations: see Fig. 1

Scales weight

The combined effect of irrigation and fertilizer management wasn't significant on saffron scale weight except in sampling 3 in early-January (Table 2). Generally, from first up to third sampling date (November 22- January 3) the scale weight decreased (Fig. 3), simultaneous with a decrease in mother corm weight (Fig. 4). However, simultaneous with replacement corms initiation (Fig. 5) as well as temperature drop in winter, scale weight took an upward trend. This procedure continued up to around sixth sampling date on March 7 and then reduced with an increase in air temperatures during late winter and early spring (Fig. 3). So far, the weight changes of corm scales during the growth cycle of saffron has not been studied in scientific researches. Based on our observations it seems that there is a close relationship between scales weight changes and air temperatures during saffron growth season. So that, in the cold months during winter the scale weight was at its highest amounts (Fig. 3). In a study on saffron concluded that removal of scales caused a reduction in leaf and replacement corms weight and stated that scales protect corms from unfavorable physical and chemical environmental factors (Sabet-Teimouri et al., 2010).

Table 2. Means squares for effects of irrigation management and fertilizer type on saffron growth properties during its growth cycle (9 samplings).

Source of variation	df	Scale weight	Mean weight of replacement corms	Replacement corms weight per clone		Corm growth rate	
		Sampling 3	Sampling 8	Sampling 5	Sampling 9	Between sampling 6 and 7	Between sampling 8 and 9
Replication	2	0.0445	1.14	0.61	4.35	0.0014	0.0238
Irrigation	1	0.0074	2.20	1.28	3.29	0.0185	0.0057
Fertilizer	2	0.0924	6.23*	1.26*	37.97*	0.0377*	0.0183
Irrigation × Fertilizer	2	0.2063*	6.40*	1.33*	37.25*	0.0294*	0.0447*
Error	10	0.0208	1.44	0.32	4.98	0.0074	0.0084

*: significant at 5% level of probability. Note: the effect of experimental factors was not statistically significant on other criteria or sampling dates.

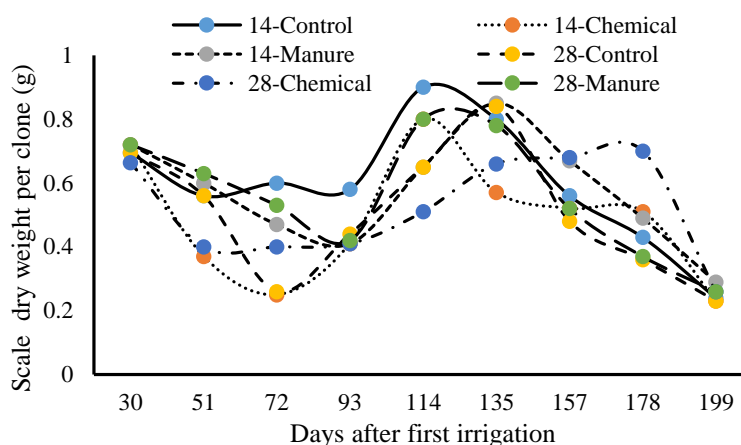


Fig 3. The trend of scale weight of corms during saffron growth cycle affected by irrigation and fertilizer management (First irrigation was done on October 21). Explanations: see Fig. 1

Mother corm weight

The effects of irrigation and fertilizer management were not significant on the mother corm weight changes during the saffron growth cycle. In all combined treatments, mother corm weight had a reducing trend from first up to the end sampling date (Fig. 4). The major part of

mother corm nutrient reserves (~50%) was consumed for flowering, root and leaf emergence before the first sampling date, where, mother corm dry weight reached from 6 g in corm planting date to less than 3 g in 30 days after first irrigation. In similar study, [Reanu-Morata et al. \(2012\)](#) stated that approximately 20–30% of the mother corm reserves is mobilized for the emergence of the roots, flowering and leaf emergence. [Gholami et al. \(2017\)](#) reported that up to 40 days after leaf emergence, the mother corm nutrient reserve is allocated to the leaf growth and then their remained reserve is used for new corm production. They stated that after this date (40 days after leaf emergence), the leaves gradually become independent but their share in the replacement corms filling is still low up to 80 days after emergence that leaf photosynthetic capacity is maximized. [Gholami et al. \(2017\)](#) with the help of results of [Lundmark et al. \(2009\)](#) concluded that during 40-80 days after emergence, 20% of mother corms nutrient is used for replacement corms filling. Therefore, it seems that about 80% of mother corms reserves are used for leaf and root production during the first 40 days of the saffron growth cycle.

The reducing trend of mother corm weight after flowering and leaf emergence was continued up to the early March, and after this date, there was only shells and the remains of corms which had no nutrients ([Fig. 4](#)). In another study, it has been observed that after flowering up to the date in which the leaves and roots reach to their maximum size, mother corm reserve consumes for vegetative growth of saffron but to a lesser extent than the carbon supplied by photosynthesis activity. After depletion of mother corm nutrient, the exponential growth stage of replacement corms is started only by relying on carbohydrate provided by the photosynthesis ([Renau-Morata et al., 2012](#)).

Replacement corms number and weight

In all combined treatments replacement corms were initiated about 50 days after first autumnal irrigation in mid-December ([Fig. 5](#)). Corm production had a nearly constant increasing trend until the end of the growth cycle. However, the rate of corm production was higher between mid-February and mid-March, while at the end of growth cycle this process was very slow. This observation is near to those reported by [Feizi et al. \(2015\)](#), which concluded that the weight and number of replacement corms had almost a linear trend from November 21 up to May 21.

Fertilizer application partially had a positive impact on corm production. The number of replacement corms in mid-May was 5.2 for chemical fertilizer, 4.5 for cow-manure application and 3.9 per clone in control treatment. In addition, at the end of growing season in spring, about 5 replacement corms were produced for each mother corm which had been planted in autumn ([Fig. 5](#)). In previous studies, the determinant role of fertilization has been reported on corm production in saffron ([Amiri, 2008](#); [Rezvani-Moghaddam et al., 2014](#)). In this plant, both vegetative and reproductive growth phases are highly dependent on nutrient availability, especially in the perennial cultivation which plants are nutrient exhausted and generally yield begin to decrease due to mineral deficiency ([Amiri, 2008](#)).

Mean weight of replacement corms affected significantly by experimental treatments in sampling 8 coincidences with the end of growth cycle ([Table 2](#)). Unlike previous studies, increase in water availability ([Fallahi et al., 2016](#); [Khashei Siuki et al., 2016](#)) and fertilizer application ([Rezvani-Moghaddam et al., 2014](#)) had not a considerable effect on the mean weight of replacement corms. However, fertilizer application improved this criterion by about 12%. On average of all combined treatments, the mean corm weight at the end of growth cycle in cow manure, chemical fertilizer, and control treatments was 6.4, 6.1 and 5.5 g, respectively ([Fig. 6](#)). This amount for 14 and 28 days irrigation intervals was 5.4 and 6.5 g, respectively. Application of cow manures in infertile soil, increases organic carbon, soil

fertility, and cation exchange capacity. Higher micro- and macro-nutrients availability is another merit of animal manures. Moreover, slow release of nutrients from cow manure during growth cycle and thereby decrease of nutrients leaching can improve saffron growth and yield (Amiri, 2008).

Replacement corm weight had a slowly increasing trend up to the end of March (sampling 7), but after that, a considerable increase in this index was observed until the leaf senesces (Fig. 8). In saffron by stopping the leaf and root development, the exponential growth stage of principal sinks of the plant viz, daughter corms, is initiated (Renau-Morata et al., 2012). In confirmation of our results, Gholami et al. (2017) concluded that fast growth of corm takes place 80 days after leaves emergence. According to our findings, the growth of leaf and root of saffron was increasing up to 80 and 110 days after first irrigation, respectively, and then decreased (Fig. 1 and 2). However, fast growth of replacement corms occurred 90 days after first irrigation (Fig. 6). These observations show that 80-110 days after first autumnal irrigation is a critical stage for photoassimilates partitioning in saffron. This critical phase has been previously reported by Behdani et al. (2016) but in their study, this period occurred 120-150 days after growth. In another survey on saffron, Juan et al. (2009) stated that during December to February (in our study up to 100 days after first irrigation), the growth of leaf and root coincided with the slow development of the stem-apex of the replacement corm.

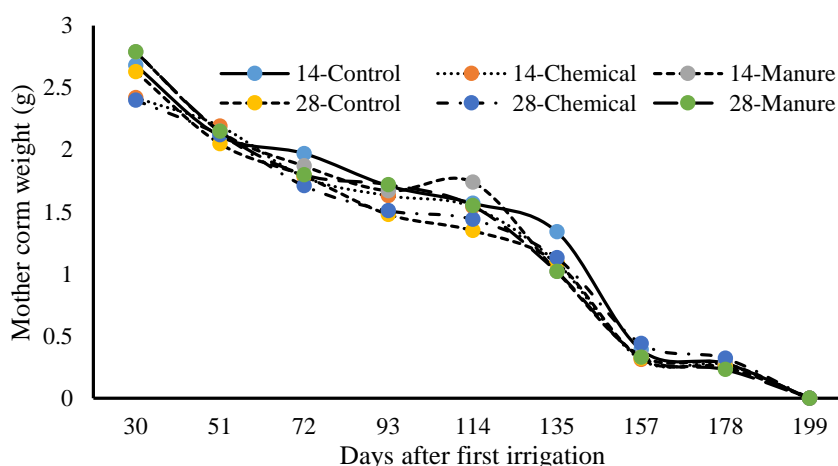


Fig 4. Changes of mother corm dry weight during saffron growth cycle affected by irrigation intervals and type of fertilizer (First irrigation was done on October 21). Explanations: see Fig. 1

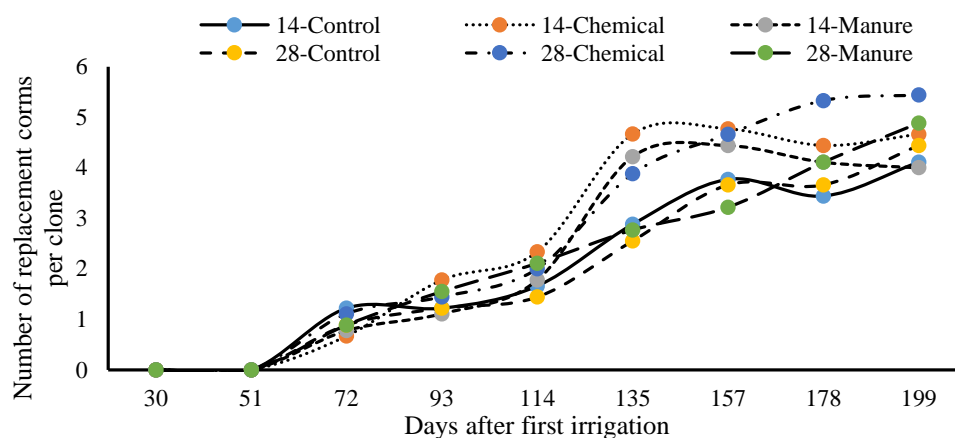


Fig 5. Changes of number of saffron replacement corms per clone during its growth cycle affected by irrigation and fertilizer management (First irrigation was done on October 21). Explanations: see Fig 1.

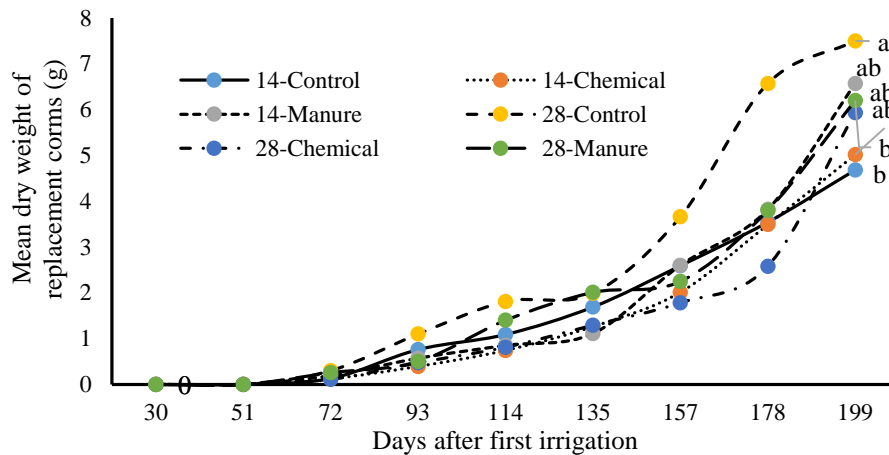


Fig 6. Effect of irrigation and fertilizer management on the mean dry weight of saffron replacement corms during its growth cycle (First irrigation was done on October 21). Explanations: see Fig 1; Note: the treatments with the same letters are not significantly different based on FLSD test at 5% level of probability. The effect of experimental factors was not statistically significant in other sampling dates.

Renau-Morata et al. (2012) from the limitation of increase in corm biomass before total leaf senescence concluded that saffron had a sink capacity limitation during growth of replacement corms. They added that reduction in the corms demand for photoassimilates can cause a sugar accumulation in leaves, which finally can accelerate leaf senescence. However, we couldn't confirm this statement, because of the rapid growth of replacement corms even at the end of growth cycle (Fig. 6). Finally, according to our observation, the highest rate of corm production (mid-February up to mid-March) takes place before the highest rate of corm filling (end-March up to mid-May) (Fig. 5 and 6). This shows that in saffron sink-production is prior to sink-filling.

Replacement corms weight per clone which represents the number of corms per clone and mean corm weight affected significantly by irrigation intervals and fertilizer application in sampling dates 5 and 9 (Table 2). In general, the highest and the lowest replacement corms weight per batch were obtained at 14 days irrigation intervals \times manure application and 14 days irrigation intervals \times no-fertilizer treatments, respectively (Fig. 7). The amount of this index took a fast increasing trend after mid-February coincidence with sampling 5. Similar to findings of Asadi et al. (2014) and Rezvani-Moghaddam et al. (2014), chemical and cow manure fertilizers application had a positive effect on corms weight per clone, in both irrigation regimes. At the end of growth cycle, cow manure and chemical fertilizers on average improved this index by 20 and 8%, respectively, compared with control. However, irrigation management had no significant effect on this index, so that corm produced per clone for 14 and 28 days irrigation intervals was 15.9 and 15 g, respectively. This result is near with statement of Renau-Morata et al. (2012) which observed an increase in water use efficiency when the soil water potential was low. This shows that saffron is an ideal crop for areas affected by drought stress. Traditionally, saffron is irrigated four times during its growth cycle, however, to obtain high flower yield, appropriate irrigation scheduling should be used (Sepaskhah & Kamkar-Haghighi, 2009). In this regards results of another study revealed that more water providing by super absorbent polymer application is an appropriate strategy for production of saffron standard corms in semi-arid areas (Fallahi et al., 2016).

Corm growth rate

The combined effect of irrigation management and fertilizers application was significant on corm growth rate between sampling 6 and 7, as well as 8 and 9 (Table 2). Although irrigation

intervals of 14 days × cow manure application produced low corm growth rate before February 14, but this treatment had the highest amount of this index from sampling 5 up to the end of growth cycle (Fig. 8). It seems that there is more need for water availability, due to the more transpiration with an increase in air temperature combined with canopy extension at the end of the growth cycle. We observed two peaks for corm growth rate (February 14 - March 7 and March 29 - April 19) (Fig. 8). Probably these points are compliance with appropriate temperature and water availability. It seems that foliar application of nutrients before these points is a suitable strategy for improvement of corm growth. However, after each peak, the amount of corm growth rate was reduced and we observed that irrigation at these times is favorable. So that, more water availability (14 days irrigation intervals) only was positive on corm growth between sampling 6 and 7 as well as sampling 8 and 9 which are located at dropping points of corm growth rate. In addition, we concluded that application of chemical and organic fertilizer was not positive on corm growth rate before February 14, but after this date, there was a positive increase in this index under fertilizer application. Totally, in all combined treatments there was a low corm growth rate up to 24 January and then was started an increasing trend (Fig. 8). These results are similar with findings of Gholami et al. (2017), which showed that the highest corm growth rates occurred about 80 days after leaf emergence.

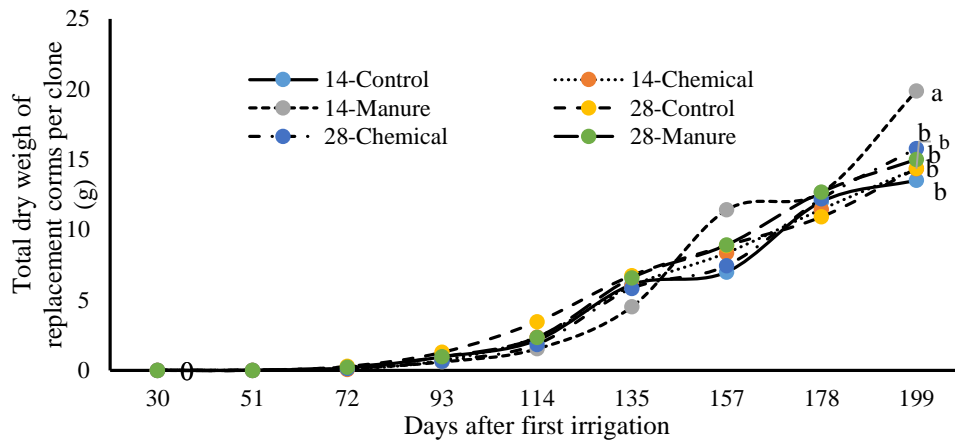


Fig 7. Effect of irrigation and fertilizer management on the dry weight of all saffron replacement corms per clone during its growth cycle (First irrigation was done on October 21). Explanations: see Fig 1; Note: the treatments with the same letters are not significantly different based on FLSD test at 5% level of probability. The effect of experimental factors was not statistically significant in other sampling dates.

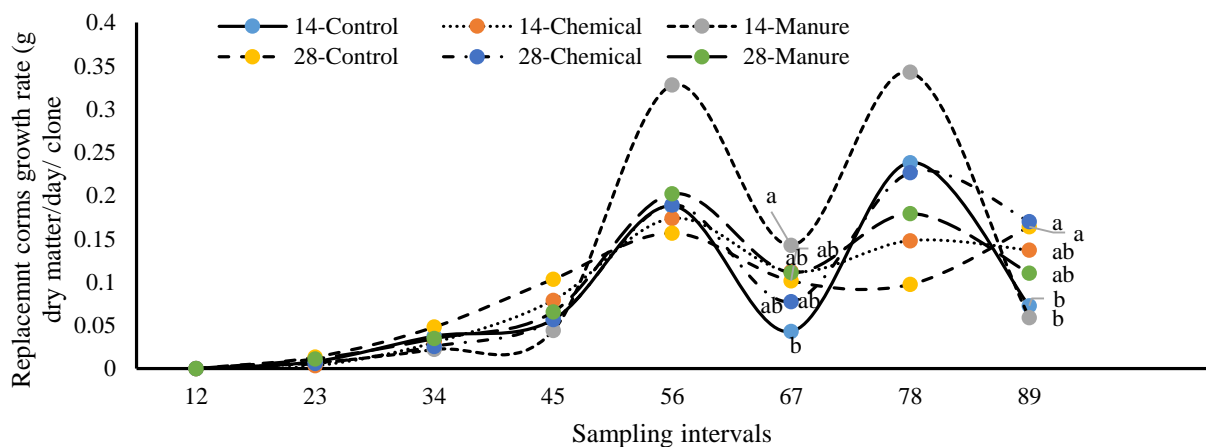


Fig 8. Effect of fertilizer type and irrigation management on the replacement corms growth rate of saffron during its growth cycle (numbers 1 to 9 in X-axis represents the sampling dates 1 to 9. For example, 12= corm growth rate between sampling 1 and 2). Explanations: see Fig. 3.

The active period of saffron replacement corm filling

There was no significant difference between treatments in terms of the time of beginning, end, and duration of the active period of saffron replacement corms filling. However, the beginning of this period was some delayed by application of fertilizers especially when water availability was more. In all treatments, the end of the corm filling active period was similar and occurred 190 days after first autumnal irrigation. Finally, at the higher level of water availability, the duration of corm filling active period was decreased by fertilizer application. A similar trend was observed for chemical fertilizer in the lower level of water consumption, but cow manure application extended this period under low water availability (Fig. 9). According to Figures 7 and 8, it seems that water and nutrient availability exert a positive impact on corm growth mainly by increasing corm growth rate than corm filling period. However, we expected that increase in water and nutrient availability expand the active period of corm filling mainly by delaying in the end of corm filling (delayed leaf senescence). The accurate assessment of this process needs more experiments. Our finding was not completely coordinated with the idea that believes, water stress decreases the seed filling period of crops (Ahmadi et al., 2009). It may be because of relatively sufficient availability of water even in the condition of increasing irrigation intervals (consumption of $3200 \text{ m}^3 \text{ ha}^{-1}$ during the growing season). This becomes more likely if we know that saffron is not watered in many cultivated Mediterranean areas and its water requirement is $3000 \text{ m}^3 \text{ ha}^{-1}$ during its growth cycle in Iran climatic condition (Gresta et al., 2008). Therefore, it is suggested that for better understating of the impact of water stress on biomass partitioning in saffron, the greater water stress is applied in future studies. In a review on saffron irrigation management Sepaskhah and Kamkar-Haghighi (2009) concluded that seasonal rainfall of 600 mm is almost sufficient for rainfed saffron production. However, in areas received 400 and 200 mm rainfall a continuous supplemental irrigation with intervals of 24 (50% ETp) and 15 (75% ETp) days is needed. Moreover, it must be considered that water requirement of saffron is different between years if the plant is used as a perennial crop. In this regards, Azizi-Zohan et al. (2009) concluded that the highest yields for the first and second years were obtained at 24 and 12 days irrigation intervals, respectively.

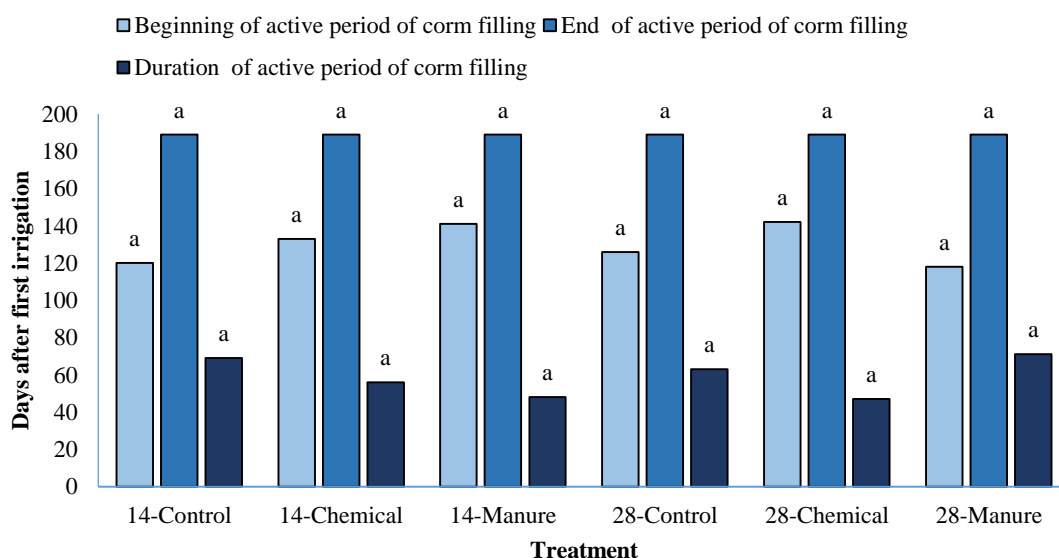


Fig 9. Influence of irrigation and fertilizer management on the time of beginning and end as well as the duration of the active period of saffron replacement corm filling. Note: the treatments with the same letters are not significantly different based on FLSD test at 5% level of probability

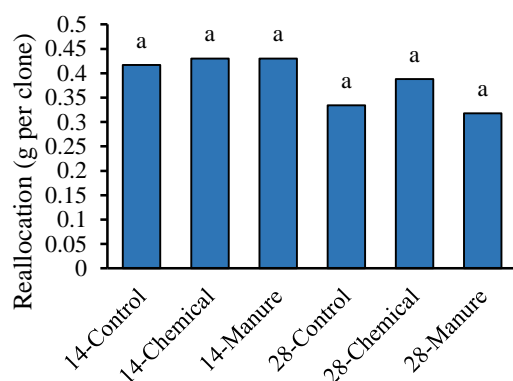


Fig 10. Effect of irrigation and fertilizer management on the reallocation of photoassimilates from leaves to replacement corms of saffron. Note: the treatments with the same letters are not significantly different based on FLSD test at 5% level of probability.

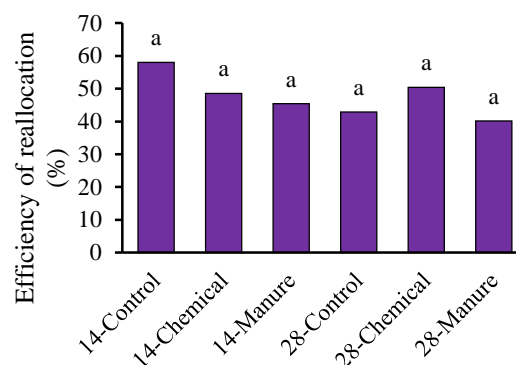


Fig 11. Effect of irrigation and fertilizer management on photoassimilates reallocation efficiency from leaves to replacement corms of saffron. Note: the treatments with the same letters are not significantly different based on FLSD test at 5% level of probability.

Remobilization of photoassimilates

Effect of irrigation regimes and fertilizer application was not significant on the amount and efficiency of photo-assimilates reallocation (Fig. 10 and 11). Similar to previous studies on wheat (Ahmadi et al., 2009) the amount of reallocation under low water availability was some lower than shorter irrigation intervals. This observation is due to the reduction in temporary reserves because of a decrease in photosynthetic activities (Ahmadi et al., 2009). Our study is the first research that has evaluated the indices such as corm growth rate, active corm filling period and reallocation of photoassimilates in saffron. Therefore, further experiments are needed for a better understanding of this characteristic and the effect of agronomic factors on them.

CONCLUSION

Water limitation is a serious problem for crop production in arid and semi-arid regions like Iran. Therefore, considering the low differences between two irrigation regimes in terms of biomass partitioning, we propose the application of 3600 m³ ha⁻¹ water, along with cow manure consumption during the first growing season of saffron. Due to organic manure beside nutritional values is important in terms of appropriate water holding capacity. This conclusion will be more defendable when we know that stigma yield (in the autumn of 2016), was 3.21 and 3.87 kg ha⁻¹ for 14 and 28 days irrigation intervals, respectively. In addition, stigma production in control (no-fertilizer), chemical and organic fertilizers treatments were 3.09, 2.90 and 4.64 kg ha⁻¹, respectively (data in Fallahi & Mahmoudi, 2018a). Our results also showed that 80-110 days after first autumnal irrigation is a critical stage for biomass partitioning in saffron. Before this period the roots and leaves are the main sinks and after that replacement corms become the major sink for assimilates storage. We propose to soil application of fertilizers be done before this period and nutrients spraying takes place after the critical stage.

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تأثیر میزان فراهمی آب و مدیریت تغذیه‌ای بر تسهیم مواد فتوسنتزی در طی فصل رشد زعفران (*Crocus sativus* L.)

حمید رضا فالاحی و سهراب محمودی

چکیده:

در این تحقیق اثر نوع کود مصرفی و مدیریت آبیاری بر نحوه توزیع مواد فتوسنتزی در بین اندام‌های مختلف زعفران بررسی شد. فاکتورهای آزمایشی شامل مدیریت کوددهی (عدم مصرف کود، کود حیوانی و کود شیمیایی (NPK) و رژیم آبیاری (FI= مصرف ۷۲۰۰ و DI=مصرف ۳۶۰۰ مترمکعب در هکتار در طی فصل رشد) بودند که در سال زراعی ۹۵-۱۳۹۴ به صورت فاکتوریل بر مبنای طرح پایه بلوک‌های کامل تصادفی مورد بررسی قرار گرفتند. وزن ریشه و برگ‌های زعفران به ترتیب تا ۷۲ و ۱۱۴ روز پس از اولین آبیاری پاییزه (DAFAI) افزایش و سپس کاهش یافت. بنه‌زایی از ۵۱، DAFI آغاز شد و حداکثر میزان آن در تیمار DI و مصرف کودهای حیوانی یا شیمیایی حاصل شد. در تمامی تیمارهای آزمایشی بنه‌زایی (حداکثر میزان آن بین ۱۱۴ تا ۱۵۷، DAFI) بر آغاز مرحلهٔ سریع پُرسدن بنه (۱۳۵، DAFI) مقدم بود و میزان هر کدام از این دو شاخص در DI بالاتر بود. وزن بنه-های دختره موجود در هر بوته در تیمار مصرف کود حیوانی \times FI حدود ۱۰ درصد بیشتر از سایر تیمارهای آزمایشی بود. سرعت رشد بنه از حدود ۵۰، DAFI افزایش سریعی پیدا کرد و حداکثر میزان آن (۳۲/۰ و ۳۴/۰ گرم بر روز در گیاه به ترتیب در ۵۶ و ۷۸ DAFI) در تیمار ترکیبی FI \times مصرف کود حیوانی مشاهده شد. دسترسی به منابع علمی مشابه با موضوع تحقیق، یک محدودیت بود. این پژوهش اولین تحقیقی بود که در آن اثر مدیریت آبیاری و کوددهی بر توزیع مواد فتوسنتزی در زعفران بررسی شد و بر اساس یافته‌های آن مصرف ۳۶۰۰ مترمکعب آب در هکتار همراه با استفاده از کود آلی، یک راهبرد سودمند برای زراعت زعفران در اولین فصل رشد این گیاه می‌باشد.

کلمات کلیدی: انتقال مجدد مواد فتوسنتزی، تسهیم زیست‌توده، دوره فعال پُرسدن بنه، سرعت رشد بنه، کود آلی