JOURNAL OF HORTICULTURE AND POSTHARVEST RESEARCH
2024, VOL. 7(4), 317-334

Journal of Horticulture and Postharvest Research

Journal homepage: www.jhpr.birjand.ac.ir

University of Birjand

Determining an appropriate integrated nutrition system for saffron (*Crocus sativus* L.) cultivation as affected by maternal corm weight

Ahmad Ahmadian[1,*], Nazanin Nazari[1] and Yaser Esmaeilian[2]

[1] *Department of Plant Production, University of Torbat-Heydariyeh, Torbat-Heydariyeh, Iran*
[2] *Department of Agriculture, University of Gonabad, Gonabad, Iran*

ARTICLE INFO

Original Article

Article history:
Received 1 March 2024
Revised 4 June 2024
Accepted 10 June 2024

Keywords:
Corm indices
Fertilization
Flower indices
Stigma
Water productivity

DOI: 10.22077/jhpr.2024.7242.1363
P-ISSN: 2588-4883
E-ISSN: 2588-6169

***Corresponding author:**
Department of Plant Production, University of Torbat-Heydariyeh, Torbat-Heydariyeh, Iran.

Email: a.ahmadian@torbath.ac.ir

ABSTRACT

Purpose: The aim of this study was to determine the response of saffron (*Crocus sativus* L.) to nutrient resources and maternal corm weights. **Research method:** The experiment was conducted as a split-plot based on a randomized complete block design with three replications. The main plots included four integrated nutrition programs (NP0: control (without fertilization); NP1: cow manure, amino acids, humic acid; NP2: slaughterhouse waste, mono-potassium phosphate, humic acid, mix (macro-micro) fertilizer; and NP3: poultry manure, ammonium nitrate, humic acid, amino acid, hormone biofertilizer, NP fertilizer, micronutrients) and the subplots included three maternal corm weights (CW1: 4-8, CW2: 8-12, and CW3: 12-16 g). **Findings:** The difference between the experimental treatments in terms of the effect on the studied traits of saffron was more significant in the second year than in the first year of the experiment. The NP3 treatment resulted in the highest values of the flower number (85.6), fresh and dry flower yield (28.21 and 5.48 g m^{-2}, respectively), and fresh and dry stigma yield (3.35 and 0.67 g m^{-2}, respectively). Also, planting the heaviest corms led to the highest values of the mentioned traits (79.9, 24.57, 4.85, 2.90, and 0.58 g m^{-2}, respectively). The highest value of corm number (312.1), corm diameter (4.27 cm), corm weight (6.86 g), and corm yield (1562.4 g m^{-2}) belonged to the NP3 treatment. The CW3 treatment obtained the highest values of the mentioned traits (322.7, 3.72 cm, 6.87 g, and 1476.5 g m^{-2}, respectively). Furthermore, the highest dry stigma water productivity (1.942 g m^{-3}) and corm water productivity (4.45 kg m^{-3}) were found under the NP3 treatment. Also, the highest value of the mentioned traits (1.681 g m^{-3} and 4.18 kg m^{-3}, respectively) was recorded in the CW3 treatment. **Research limitations:** No limitations were identified. **Originality/Value:** The results of this research clearly show the profound importance of the characteristics of the maternal corms and the integrated nutrition in changes in saffron yield. Overall, we conclude that the NP3CW3 treatment is the best treatment for obtaining the highest values of saffron flower and corm indices as well as the stigma and corm water productivity.

INTRODUCTION

Medicinal plants are the main and essential elements of the indigenous medical systems worldwide (Hosseinzadeh et al., 2015). Currently, the dependence of developing countries on the herbal medicinal sources is much higher than on the modern medicinal sources. According to the estimates, about 80% of the population of these countries depends on the traditional medicine and the use of medicinal sources for medical treatment and healthcare (Tareen et al., 2016). Nowadays, the demand for the use of the medicinal plants for medicinal and medical purposes, especially in traditional medicine in different countries, is increasing rapidly, and this issue has increased the economic importance of the medicinal plants (Agra et al., 2007). The prominent advantage of medicinal plants cultivation in the arid and semi-arid areas is that some environmental stresses can stimulate the plant to produce secondary metabolites, which may improve the crop quality, thereby pharmaceutical and economic superiority of the medicinal plants in these regions rather than other regions (Omidbaigi, 2000).

Saffron (*Crocus sativus* L.) is a botanically annual and agronomically perennial plant species belonging to the Iridaceae family, which is widely cultivated in the arid and semi-arid regions, especially in Iran (Fallahi et al., 2021). Saffron has a variety of uses in food, industry, and medicine, as well as cosmetics and sanitary products (Ben El Caid et al., 2020; Leone et al., 2018; Nazari & Feizi, 2021). The value and importance of saffron are due to its significant biochemical compounds, including sugars, minerals, fats, vitamins, and secondary metabolites, including terpenes, flavonoids, anthocyanins, and carotenoids, among which carotenoids are the most important because of the color and taste properties of saffron (Gismondi et al., 2012; El Grah et al., 2022).

Soil is known as the substrate for plant growth and development, and its fertility and quality are the most essential factors for the sustainable production of crops (Ayoub, 1999). In the past few decades, Iranian farmers have heavily depended on chemical fertilizers to provide the nutrient requirements of crops that, in addition to reducing the production growth rate and the stability of crop production, has caused a decrease in the biodiversity, especially in fauna and flora of the ecosystem, water and soil resources pollution and numerous harmful effects on the health of many kinds of living organisms, especially humans (Esmaeilian et al., 2022b). In such a situation, it is essential to choose a plant nutrition system that, in addition to providing a balanced supply of nutrients, is compatible with the conditions of the agro-ecosystem and causes the least damage to the living and non-living components of the ecosystem. In recent years, integrated nutrient management (INM), as an environment friendly approach characterized by a balanced mixture of the inorganic, organic and biological compounds, has received much attention (Janssen, 1993). The purpose of INM is to achieve the best combination of fertilizers, which, while using sufficient and balanced types of fertilizers, increases the effectiveness of plant nutrition on the improvement of quantitative and qualitative traits of the crops, while maintaining the health and quality of the soil (Selim, 2020). Several researches show a positive and significant response of saffron to INM systems compared to applying fertilizer compounds alone. For example, Sarfraz et al. (2023b) reported that the integrated nutrition systems improved saffron flower and stigma indices by 35-70% and saffron corm indices by 35-96%. Kirmani et al. (2022) conducted a large-scale study and concluded that the highest yields of saffron flowers and corms were obtained in farms where the integrated nutrition system was implemented. The results of another research showed that the integrated application of organic and inorganic nitrogen sources has the potential to improve the quality of saffron stigma (Sarfraz et al., 2023a). Studies have shown significant and positive effects of combined application of cow manure (Turhan et al., 2007), poultry manure (Saeidi Aboueshaghi et al., 2022), vermicompost (Feli et al., 2018), and biological fertilizers (Ahmadi & Nazari Alam, 2015; Alizadeh et al., 2018) with chemical fertilizers on the growth and yield of saffron.

One of the fertilizer sources that has been considered as an alternative to chemical fertilizers is animal waste that, if properly managed, can be an attractive option in the sustainable agriculture and, as a good source of nutrients, can play an influential role in improving the soil organic matter and fertility, and reduce the costs of the crop nutrition system (Roy et al., 2013). This organic amendment also plays an essential role in improving soil health (Adesina et al., 2020). The Organic fertilizers, unlike the chemical fertilizers, which have high solubility and availability (Barker & Pilbeam 2007), need more time to be mineralized and provide their elements to the plant (Tejada et al., 2014). For this reason, the release of nutrients from these fertilizer sources is done gradually, and thereby, the process of absorbing their elements by plants takes place over a long time. The use of organic and biological fertilizers has positive ecological effects, especially on the physical, chemical, and biological properties of soil, which is closely related to the food quality and safety, environmental health, and human health maintenance (Alfa et al., 2014).

Biofertilizers, containing various microorganisms (e.g., bacteria, fungi, and algae) and growth-promoting compounds (e.g., plant hormones and amino and organic acids) as ecofriendly, low-cost, and effective compounds, play an essential role in the implementation of sustainable agricultural strategies to replace chemical fertilizers and reduce off-farm inputs in low input farming systems (Kawalekar, 2013; Al-Taey et al., 2019; Azarmi-Atajan & Sayyari-Zohan, 2022). Microorganisms in biofertilizers cause the mineralization of organic compounds and the conversion of inorganic compounds from non-absorbable form to absorbable form through various biological processes (Ekta et al., 2017). By improving the physical, chemical, and biological characteristics of the soil, these materials improve soil fertility and, ultimately, increase the growth and quantitative and qualitative yield of crops (Abdel-Raouf, et al., 2012; Al-Taey et al., 2019).

Saffron is a plant whose growth and yield are strongly affected by the environmental and management factors among which, plant density, maternal corm properties, and plant nutrition are critical (Temperini et al., 2009). It has been determined that to produce saffron flowers, a minimum amount of saffron corm weight and size is required (Douglas et al., 2014). It has been reported that planting larger maternal corms due to more reserves, not only improves the vegetative growth of saffron and flower production in the first year, but also, due to better growth and use of environmental resources, leads to more daughter corms production and, ultimately, to more flower and corm yield during the consecutive years (Renau-Morata et al. 2012; Fallahi et al., 2017). Ebrahimi et al. (2021) reported a significant increase in traits such as flowers number, style-stigma dry weight, number and weight of daughter corms as a result of planting large-sized corms. The results of another research showed that planting heaver maternal corms (>12 g) caused earlier flowering and more extended flowering period, which resulted in the significantly higher flower and stigma yields. Also, corm yield was significantly higher in plots with higher maternal corm weight (Alie et al., 2023).

The important challenge facing the agricultural sector is the enhancement of per person crop production in line with the population growth on the one hand, and the limitation of environmental resources, especially water, on the other hand. This issue is more vital in the arid and semi-arid areas, which has utilized the strategies of reducing water consumption or increasing crop production per unit of water consumption in order to improve water productivity making it an inevitable issue. This issue, in the case of saffron plant, which is produced in the important saffron growing areas in the world, including Iran, by basin irrigation, is especially important. Furthermore, the complexity of the saffron plant and its variable responses to the environmental and management factors are among the main challenges in the main areas of saffron cultivation, especially in Iran. Saffron nutrition and choosing the proper fertilizing system, which, like the eco-friendly agricultural system, guarantee the achievement of the appropriate yields, have always been parts of the basic challenges in the saffron production. On the other hand, the interaction effects of maternal corm characteristics and other effective factors in the growth and yield of saffron are other important questions in the saffron cultivation management. Therefore, the purpose of this research was to compare different types of the integrated nutrition systems in terms of their effect on the quantitative characteristics and water productivity of saffron flowers and corms and to choose the best nutrition system according to different maternal corm weights.

MATERIALS AND METHODS

Site description

The experiment was conducted at the research farm of University of Torbat Heydarieh, Torbat Heydarieh, Iran (59° 133′ E, 35° 20′ N, and 1450 m a.s.l.) during two consecutive growing seasons (2016-17 and 2017-18). The experimental site location is shown in Fig. 1. According to the Köppen climate classification, the area has an arid climate. The average annual temperature of the area is 14.3 °C, while the minimum and maximum temperatures are -4.3 and 33.5 °C in February and August, respectively. The average long-term annual rainfall is 274.8 mm and, mainly, occurs between January and April. The average annual relative humidity is 46%, with a minimum of 33% and a maximum of 64% during August and February, respectively. Monthly rainfall and average maximum and minimum temperature data of the study area during the experiment years are given in Fig. 2. The soil of the experimental site was classified as clay loam with low organic matter. The soil with electrical conductivity (EC)=2.19 dS m^{-1} and pH=8.01 is classified as normal soil (Scherer et al., 1996). Some physicochemical properties of the experimental field soil are presented in Table 1.

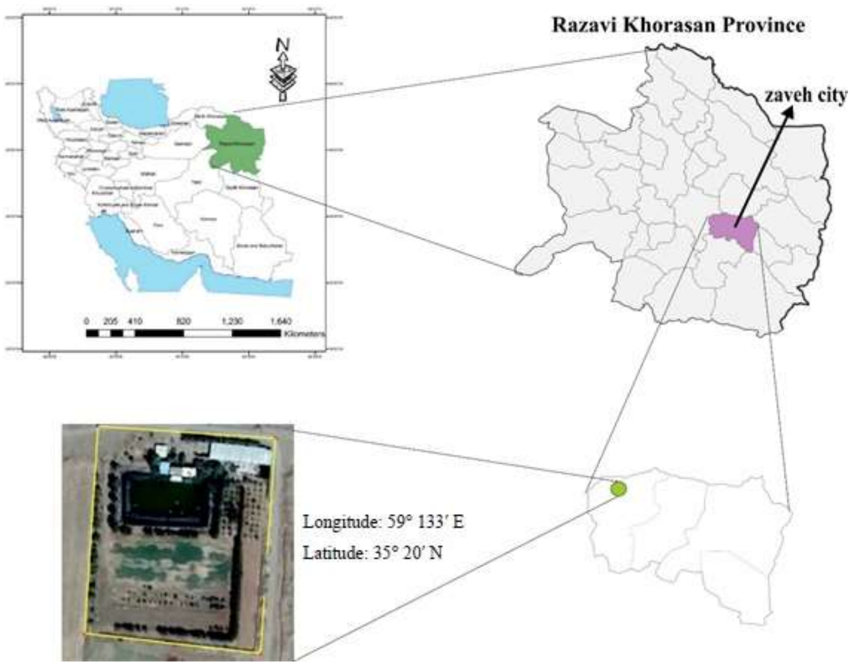

Fig. 1. Location of the studied area, Zaveh, Torbat Heydarieh, Razavi Khorasan province.

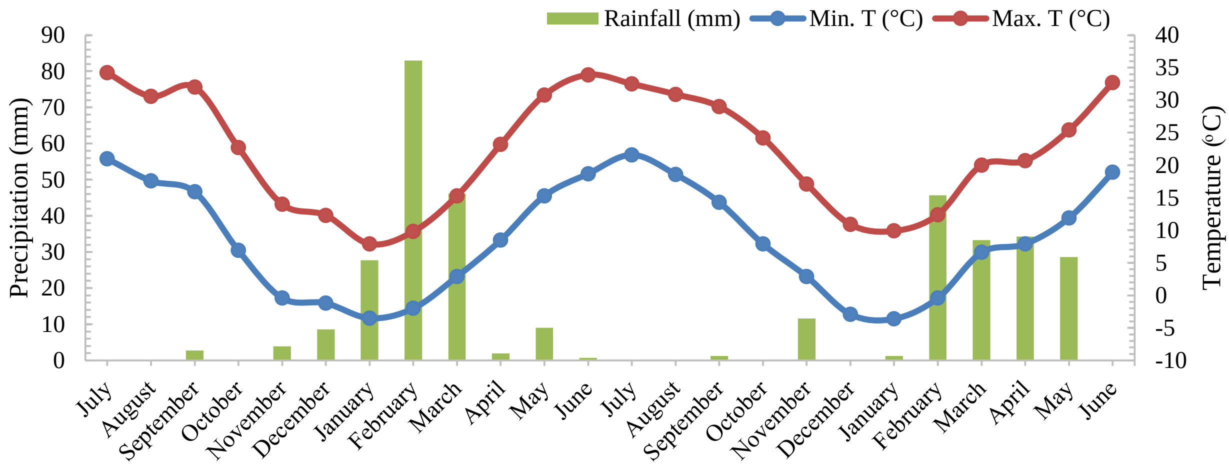

Fig. 2. Regional meteorological records of the experiment site during the two growing seasons (2016-17 and 2017-18).

Table 1. Physical and chemical properties of experimental site soil.

Soil texture	Sand	Silt	Clay	$CaCO_3$	Total N	Organic carbon	Available P	Available K	pH	EC
	%						(mg kg^{-1})		-	dS m^{-1}
Clay loam	13	53	34	17.5	0.049	0.51	28	360	8.01	2.19

Experimental design and treatments

The field experiment was conducted as split plot based on a randomized complete block design with three replications. The main plots included four nutrition treatments described below, and the subplots consisted of three levels of maternal corm weight groups (4-8, 8-12, and 12-16 g).

One of the main objectives of this research was to investigate the effects of the integrated nutrition systems on the studied characteristics of saffron and to choose and recommend the best fertilizer combination for the saffron farming system. So, for the selection of experimental treatments, the literature review and the opinions of experts in the agricultural sector were used. The four levels of the nutrition programs were:

Treatment 1) Control (no fertilization).

Treatment 2) before planting (July 2016), 3400 kg ha^{-1} cow manure was incorporated into the soil. After planting, 5 L ha^{-1} humic acid was applied during the first irrigation (September 2016). Then, in November 2016, the amino acid (0.3 kg ha^{-1}) and humic acid (5 L ha^{-1}) fertilizers were applied with irrigation and repeated at the same rate in January, March, September, November 2017, and January 2018.

Treatment 3) before planting (July 2016), 6600 kg ha^{-1} slaughterhouse waste was mixed with the soil. 50 kg ha^{-1} mono-potassium phosphate, 2 kg ha^{-1} Fe chelated fertilizer and 4 kg ha^{-1} humic acid powder fertilizer was applied during the first irrigation (November 2016). In January 2017, 15 kg ha^{-1} mix (macro-micro) fertilizer (N, P, K, Fe, Zn, Mg, and Cu chelates) was applied during the irrigation operation. In March 2017, 5 L ha^{-1} humic acid fertilizer was applied with irrigation. 25 kg ha^{-1} 15-5-30 NPK fertilizer and 4 kg ha^{-1} humic acid powder fertilizer were applied as incorporated within the irrigation water. In November 2016 and January 2017, the fertilization program of the previous year was repeated. In March 2017, 5 L ha^{-1} humic acid fertilizer was incorporated into the irrigation water.

Treatment 4) before planting (July 2016), 3400 kg ha^{-1} poultry manure was incorporated into the soil. After planting (September 2016) 400 kg ha^{-1} ammonium nitrate and 300 kg ha^{-1}

humic acid granular fertilizer were added to the soil before the first irrigation. In November 2016, 100 kg ha^{-1} urea, 25 kg ha^{-1} 20-20-20 NPK, 1 kg ha^{-1} amino acid, and 200 kg ha^{-1} sulfur granular fertilizers were applied as incorporated within the irrigation water. In January 2017, 1 liter per 1000-liter water of hormone biofertilizer (containing 250 ppm of auxin, gibberellin, and cytokinin), 40-30 NP fertilizer, and micronutrients fertilizer (containing 0.3, 0.4, 0.4, 0.25, 0.8, and 0.65% of B, Cu, Fe, Mg, Mn, and Zn, respectively) were foliar sprayed two times. Also, 3 kg ha^{-1} humic acid powder fertilizer was applied and incorporated into the irrigation water. This nutrition program was repeated in September and November 2017 and January and March 2018.

The chemical properties of the organic fertilizers applied in the experiment are presented in Table 2. Urea (150 kg ha^{-1}), super phosphate triple (120 kg ha^{-1}), and potassium sulphate (100 kg ha^{-1}) were used as fertilizer source of N, P, and K fertilizer, respectively.

Experiment layout and agronomic practices

After plowing, disk, and leveling, the experimental plots were constructed manually with a 4.5 m^2 area (2.25 m × 2.0 m), 1.0 m distance between the adjacent plots, and 1.5 m between the blocks. According to the nutrition program treatments, the required fertilizers were incorporated into the soil of each plot. The saffron corms used in this experiment were provided from Zaveh, Razavi Khorasan Province ecotype. Based on the saffron corm weight treatments, the maternal corms were separated according to each weight group. Saffron corms were planted as the basin method in July 2016 at 100 corms m^{-2} density at 15 cm soil depth. Therefore, no new planting was done in the second year. Irrigation of saffron was carried out as the basin irrigation. Table 3 shows the irrigation date and volume during the saffron growth period. Five days after the first irrigation, breaking the soil crusting was done manually. Weeding was done manually in two stages in December and January of each experiment year.

Measurements and data collection

Saffron flowers were accounted and picked up daily. The duration of the saffron flowering stage in the first and the second years was 5 to 30 November 2016 and 7 November to 2 December 2017, respectively. The flowers were transferred to the laboratory and weighed using a precision digital scale (±0.0001 g), and then the fresh flower yield was calculated. Then, saffron stigmas were separated from the flowers, weighed, and recorded as fresh stigma yield. After drying the flowers and stigmas in the shade at room temperature, dry flower yield and dry stigma yield were measured.

Table 2. Chemical analysis of organic fertilizers used in the experiment.

Parameter / Fertilizer	O.C	N	P	K	Zn	Cu	Fe	Mn	EC	pH
	%				mg kg $^{-1}$				dS m^{-1}	-
Cow manure	33.1	2.2	0.8	0.9	56.3	35.0	743	70.4	5.7	6.8
Poultry manure	43.7	4.5	1.4	1.9	281.1	26.8	1174	47.6	8.5	6.4
Vermicompost	23.9	2.7	1.5	1.3	41.5	8.1	143	28.5	6.3	7.8
slaughterhouse waste	61.4	6.3	2.0	0.71	76.2	22.7	1038	19.9	4.9	6.1

Table 3. Irrigation dates and volumes applied during the saffron growth period.

Irrigation date					
First year	2016-10-17	2016-11-23	2017-01-04	2017-02-08	2017-04-01
Second year	2017-10-19	2017-11-20	2018-01-09	2018-02-12	2018-03-28
Irrigation volume (m^3 ha^{-1})					
First year	750	600	530	560	550
Second year	630	620	570	580	580

At the end of each growing season (26 and 27 July 2017 and 2018, respectively), daughter corms were harvested from the 0.5 m^2 area of each plot, and the related traits such as replacement corm number, diameter, weight, and corm yield were determined. The corm weight and diameter were determined from 10 randomly selected corms.
The dry stigma and corm water productivity were calculated using the following formula (1):

$$\text{Dry stigma/corm WP (g/kg m}^{-3}\text{)} = \frac{\text{Dry stigma/corm yield (g/kg ha}^{-1}\text{)}}{\text{Irrigation water applied (m}^{3}\text{ ha}^{-1}\text{)}} \qquad (1)$$

Statistical analysis

Data were subjected to analysis of variance (ANOVA) using SAS software version 9.2 (SAS, 2008), and the difference between treatment means was separated using the least significant difference test (LSD) at a 5% probability level.

Table 4. Mean comparison for the saffron flower indices as affected by nutrition programs and maternal corm weight.

Treatments	Flower number (no. m^{-2})		Fresh flower yield (g m^{-2})		Dry flower yield (g m^{-2})		Fresh stigma yield (g m^{-2})		Dry stigma yield (g m^{-2})	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Nutrition program (NP)	**	**	**	**	**	**	**	**	**	**
NP0 (control)	27.6^{d}	39.9^{d}	10.06^{d}	11.94^{d}	1.94^{c}	2.45^{c}	0.93^{c}	1.46^{d}	0.17^{c}	0.29^{d}
NP1	33.1^{b}	53.1^{c}	13.12^{b}	15.25^{c}	2.38^{b}	3.01^{c}	1.22^{b}	1.88^{c}	0.22^{b}	0.36^{c}
NP2	30.3^{c}	74.6^{b}	11.58^{c}	24.45^{b}	2.18^{b}	4.75^{b}	1.05^{c}	2.97^{b}	0.20^{bc}	0.59^{b}
NP3	43.3^{a}	85.6^{a}	16.46^{a}	28.21^{a}	2.78^{a}	5.48^{a}	1.62^{a}	3.35^{a}	0.27^{a}	0.67^{a}
Corm weight (CW)	**	**	**	**	**	**	**	**	**	**
CW1	30.4^{c}	45.4^{c}	11.56^{c}	15.06^{c}	1.92^{c}	3.03^{c}	1.06^{c}	1.95^{c}	0.20^{b}	0.38^{c}
CW2	33.6^{b}	64.5^{b}	12.84^{b}	20.28^{b}	2.30^{b}	3.89^{b}	1.21^{b}	2.41^{b}	0.22^{ab}	0.48^{b}
CW3	36.8^{a}	79.9^{a}	14.02^{a}	24.57^{a}	2.72^{a}	4.85^{a}	1.35^{a}	2.90^{a}	0.24^{a}	0.58^{a}
NP×CW	NS	*	NS	*	*	*	NS	*	NS	*
NP0CW1		25.7^{h}		8.48^{g}	1.70^{g}	2.04^{f}		1.10^{i}		0.22^{g}
NP0CW2		43.7^{g}		11.43^{f}	1.90^{efg}	2.11^{f}		1.35^{h}		0.28^{f}
NP0CW3		50.3^{efg}		15.91^{e}	2.20^{d}	3.20^{e}		1.94^{f}		0.38^{e}
NP1CW1		42.3^{g}		10.42^{f}	2.08^{def}	2.24^{f}		1.56^{gh}		0.27^{f}
NP1CW2		49.0^{fg}		15.92^{e}	2.34^{cd}	3.19^{e}		1.71^{fg}		0.34^{e}
NP2CW3		68.0^{c}		19.41^{d}	2.74^{b}	3.61^{e}		2.38^{e}		0.48^{d}
NP2CW1		54.3^{ef}		18.96^{d}	1.78^{fg}	3.41^{e}		2.32^{e}		0.46^{d}
NP2CW2		77.0^{ef}		26.19^{b}	2.22^{d}	4.90^{cd}		3.19^{c}		0.64^{b}
NP2CW3		92.3^{c}		28.21^{b}	2.54^{bc}	4.95^{ab}		3.42^{b}		0.68^{b}
NP3CW1		59.3^{d}		22.35^{c}	2.14^{de}	4.43^{d}		2.81^{d}		0.57^{c}
NP3CW2		88.3^{b}		27.56^{b}	2.80^{b}	5.37^{bc}		3.38^{c}		0.66^{b}
NP3CW3		109.0^{a}		34.73^{a}	3.40^{a}	6.65^{a}		3.86^{a}		0.78^{a}
C.V (%)	10.63	9.21	9.96	7.22	9.71	8.72	13.04	6.77	11.27	6.13

* and **: Significant at $p<0.05$ and $p<0.01$, respectively. NS: Non-significant according to the LSD test.
Means within each column with same letters are not significantly different by LSD test ($p<0.05$).
NP0 to NP3 indicate nutrition programs. CW1 to CW3 indicate maternal corm weights.

RESULTS AND DISCUSSION

Flowering indices

All the nutrition treatments increased the flower number (FN) compared to the control treatment. In the first year, the highest value (43.3 flowers m^{-2}) was obtained from the NP3 treatment, and the NP1 treatment was ranked next with 33.1 flowers m^{-2}, that increased the FN by 56.9 and 19.9%, respectively, compared to the control. In the second year, the NP3 treatment, achieved 85.6 flower m^{-2}, caused the highest increase than control (114.5%), and the NP2 treatment, with a value of 74.6 flowers m^{-2} (86.0% increase) was ranked in second place (Table 4). It seems that the NP3 treatment with a suitable combination of organic, biological and chemical fertilizers has a better balance of nutrients. For this reason, it has provided better growth conditions for the saffron plant that, ultimately, led to more flower production. Probably, the increase in the FN as a result of the application of the NP2 treatment is more due to the application of slaughterhouse waste in this treatment because this organic fertilizer, not only increases the organic matter in the soil but, is also able to release various hormones and amino acids that can increase photosynthesis and assimilates production by the plant (Besharati & Saffari, 2022). Changing the trend from the chemical fertilizers to organic and biological fertilizers in saffron cultivation is vital. Several studies have shown favorable responses of saffron to the use of organic and biological fertilizers alone or in combination with chemical fertilizers (Ahmadi & Nazari Alam, 2015; Ekta et al., 2017; Ebrahimi et al., 2021; Esmaeilian et al., 2022b).

Planting heavier maternal corms increased the emergence of saffron flowers so that in the first year, the CW2 (8-12 g) and CW3 (12-16 g) treatments increased the FN by 10.4 and 21.05%, respectively, and 42.0 and 75.9% in the second year, respectively, compared with the small corms (4-8 g). The interaction effect of the experimental factors on the FN in the second year was significant so that the highest value (109.0 flowers m^{-2}) was obtained from the NP3CW3 treatment and followed by the NP3CW2 treatment with 88.3 flowers m^{-2}. Table 4 also shows that the nutrition treatments had more effect on the flowering of small corms than on the large ones, which was more evident in the case of the smallest corms (4-8 g). In a situation where one of the main obstacles and limitations in the crop production in the arid and semi-arid regions is the organic matter content as well as the poor nutrients in the soil (Reynolds, 2017), the integrated use of chemical, organic and biological fertilizers along with the cultivation of appropriate maternal corms can significantly increase the probability of success in saffron cultivation.

The fresh flower yield (FFY) significantly responded to the experimental treatments. The NP3 treatment with the FFY of 8.2 and 28.2 g m^{-2} obtained the highest value in the first and second year, respectively. While the lowest values (5.0 and 11.9 g m^{-2}, respectively) belonged to the control (Table 4). The combined use of nitrogen chemical fertilizer with poultry manure in this treatment, in addition to lowering the ratio of C/N, has prevented the lack of nitrogen required by the plant during the early growth period and through the acceleration in mineralization and release of minerals from organic fertilizer has provided the nutritional requirements of the plant (Salehi et al., 2014). Increasing the maternal corms weight led to an increase in the FFY, gradually. This increase in the second (medium-weighted corms) and third (big corms) levels compared to the first level (small corms), was 11.1 and 21.3%, respectively, and in the second year was 34.7 and 63.1%, respectively (Table 4). The saffron corm characteristics can determine the growth status of this plant in the following years. It has been found that the corm properties have a high effect on the emergence of flowers and the flower yield of saffron (Esmaeilian et al., 2022a). A comparison of the mean values of the interaction effect treatments showed that the NP3CW3 treatment achieved the highest FFY (34.7 g m^{-2}) and the NP2CW3 treatment, with a value of 28.2 g m^{-2} ranked in the second place

(Table 4). As mentioned above, the growth and yield of saffron are highly dependent on the growth situation of replacement corms in the previous year. Therefore, planting corms with appropriate size and weight and optimum reservoir status can improve the regrowth and flower yield of saffron in the following year (Renau-Morata et al., 2012; Koocheki & Seyyedi, 2015).

The dry flower yield (DFY) was significantly influenced by the experimental treatments in all the experiment years. The data in Table 4 clearly show that the nutrition program treatments had different effects on this trait. The highest DFY obtained in the first year (1.39 g m^{-2}) belonged to the NP3 treatment, and the NP1 (1.19 g m^{-2}) and NP2 (1.09 g m^{-2}) treatments were ranked in second and third place, respectively. The NP3 treatment in the second year also had the highest effect on the improvement of this trait by obtaining a DFY of 5.48 g m^{-2}. The NP2 and NP1 treatments were placed in the following places with values of 4.75 and 3.01 g m^{-2}, respectively. Optimum formation of saffron replacement corms can improve the growth characteristics and production of saffron flowers in the following year, due to the proper agronomic management operations (de Juan et al., 2009). The results of this research show that the integrated nutrient management by means of the effective and homogeneous combination of different types of fertilizers leads to their adequate and balanced use in terms of the quantity and quality, that results in the nutrient uptake at the right time and during the plant growth stages. This ultimately, can lead to better growth and higher yields (Selim, 2020). Planting corms with higher weight improved the DFY. By increasing the maternal corm weight from the first level to the second and third level, the values of this trait increased by 20.8 and 41.7% in the first year and 29.0 and 60.1% in the second year, respectively (Table 2). The mean comparison of the interaction treatments (Table 4) showed that in both years of the experiment, the plants that were treated with the fourth nutrition program and had the highest weight of the maternal corm (NP3CW3 treatment) achieved the highest DFY (1.70 and 6.65 g m^{-2} in the first and second year, respectively). A more effect of the fertilizer treatments on the small than large corms was also observed regarding DFY (Table 4). Koocheki and Seyyedi (2015) stated that although the amount of nutrient reserve of maternal corm has a determining role in the growth and production of saffron flowers, the soil nutrient content, especially from the second year of growth, when the reserves of maternal corms decreased and the growth of replacement corms increased, is more critical.

The variation in the fresh stigmas yield (FSY) as a result of the implementation of different nutrition programs and plantation of corm with different weight groups was also significant. In the first year, the NP3 treatment achieved the highest value (1.62 g m^{-2}), and the NP1 treatment, with a value of 1.22 g m^{-2}, was in second place. In the second year, the NP3 treatment also obtained the highest value (3.35 g m^{-2}), while the NP2 treatment, with a value of 2.97 g m^{-2}, was in second place (Table 4). Numerous researchers have emphasized that the growth and yield of saffron are greatly influenced by the plant environment and nutritional condition of the corms (Lage & Cantrell, 2009; Siracusa et al., 2011; Ghorbani et al., 2019). The use of humic acid fertilizer in the integrated nutrition systems can be considered an essential factor in achieving these results. It has been reported that humic acid, as a growth stimulating fertilizer, directly or indirectly increases the nutrients uptake and improves plant physiological processes (Nourihoseini et al., 2016). By increasing the maternal corm weight from the first to the second and third levels, the FSY increased by 14.1 and 27.4% in the first year and by 23.6 and 48.7% in the second year, respectively (Table 4). The mean comparison of interaction effect treatment in the second year also showed that the NP3CW3 treatment had the highest value (3.86 g m^{-2}), and the second place (3.42 g m^{-2}) was related to the NP2CW3 treatment (Table 4).

The response of dry stigma yield (DSY) to the experimental treatments was also almost similar to the FSY, although its increase was higher than the FSY. Applying the second to fourth nutrition programs in the first year caused 29.4, 17.6, and 58.8%, and in the second year, 24.1, 103.4, and 130.0% increase, respectively, compared to the control (Table 4). This increase in the case of corm weight treatments from the second and third levels compared to the first level was 7.3 and 16.7% in the first year and 26.3 and 52.7% in the second year, respectively (Table 4). Our results also indicated that applying the NP3CW3 treatment obtained the highest DSY (0.78 g m^{-2}), and the NP2CW3 treatment placed in the next rank (0.68 g m^{-2}). Temperini et al. (2009) stated that corm weight and nutrition management are two determining factors for saffron yield. Khorramdel et al. (2015) concluded that maternal corm characteristics have more importance than other agronomic factors affecting saffron production. The results indicate that the selection of appropriate maternal corm and implementation of integrated nutrition that provides sufficient and balanced macro and micro elements required by the saffron plant are key factors in saffron production.

Corm indices

Replacement corm number (RCN) in both years of the experiment showed a significant response to the nutrition program treatments. In the first year, the NP3 treatment showed the highest value (163.4 corm m^{-2}), although it didn't show a significant difference from the NP1 treatment. In the second year, different results were obtained, so the highest value (319.6 corm m^{-2}) belonged to the NP2 treatment, and the NP1 treatment ranked second with 314.8 corm m^{-2} (Table 5). Although the saffron plant is considered an adaptable and low-input plant in terms of the need for fertilization and supply of nutrients (Gresta et al., 2008), the results of numerous researches show a reasonable response of this crop to the use of chemical and biological fertilizers (Koocheki & Seyyedi, 2015; Ghanbari et al., 2019; Esmaeilian et al., 2022a,b). As shown in Table 5, the variation in the weight of maternal corms hadn't any significant effect on the RCN in the first year while, in the second year, the CW2 and CW3 treatments without statistically significant differences with values of 313.6 and 322.7 corm m^{-2}, respectively obtained higher values than control (278.8 corm m^{-2}). It seems that planting corms with more weight due to more nutrition reserves and producing an extensive root system that can absorb more water and nutrients resulted in the production of more replacement corms by more buds (Renau-Morata et al., 2012; Koocheki et al., 2014).

Replacement corm diameter (RCD) significantly responded to the nutrition program treatments. As Table 5 shows, all the nutrition treatments increased the RCN than the control; however, the highest value in the first and second year (3.74 and 8.54 cm, respectively) was obtained from NP3 treatment, which showed a 70 and 78% increase, respectively compared to control. Planting heavier corms increased the RCN, so a 56.5 and 39.5% increase in RCN in the first and second year of the experiment, respectively, was achieved due to planting 12-16 g maternal corms (Table 5). Among the interaction treatments, the highest values in two years of the experiment (5.09 and 5.15 cm, respectively) were obtained due to planting 12-16 g maternal corms under the third nutrition program (Table 5).

Replacement corm weight (RCW) was also significantly influenced by the experimental treatments. The highest value in the first year (5.42 g) was obtained due to the implementation of the fourth nutrition program. However, it didn't show a significant difference with the third nutrition program (4.97 g). Similar results were obtained in the second year, and the NP3 and NP2 treatments without any significant difference had the highest effect on the increase in the RCW by obtaining values of 6.86 and 6.65 g, respectively (Table 5). The difference in the RCW was very evident regarding the levels of maternal corm weight so that the increase in corm weight from the first to the second and third levels led to 28.2 and 53.7% increases in the first year and 24.7 and 48.7% in the second year, respectively (Table 5). Amirnia et al. (2014), by comparing the effects of maternal corm weight on saffron characteristics, concluded that corms with a weight of 10 grams and above are the most suitable corms to obtain more replacement corms with a higher weight, while corms with a weight of 6 grams and below are not recommended for cultivation. The results of our experiment also indicated that planting the heaviest maternal corms and applying the fourth nutrition program in both years of the experiment had the most significant effect (6.73 and 8.82 g, respectively) in improving this trait. The second rank in both years of the experiment (5.89 and 7.78 g, respectively) belonged to the third nutrition program and the third level of maternal corm weight (Table 5).

The corm yield (CY) was also significantly affected by the experimental treatments. The NP3 treatment achieved the highest CY in both years of the experiment however; its effect was more noticeable in the second year so that the CY as a result of the implementation of the fourth nutrition program was 15.5% in the first year and 26.3% in the second year (Table 5). Rasouli et al. (2014) also compared different types of nutrient systems on the characteristics of saffron and, concluded that the integrated nutrition system consisting of organic, biological and chemical fertilizers had the highest effect on the corm yield. Planting the maternal corms with higher weight resulted in higher CY values, so the CW2 and CW3 treatments showed 8.6 and 15.2% increase in the first year, respectively, and 7.2 and 13.2% increase in the second year, respectively, compared to the CW1 treatment (Table 5).

Table 5. Mean comparison for the saffron corm indices as affected by nutrition programs and maternal corm weight.

Treatments	Corm number (no. m^{-2})		Corm diameter (cm)		Corm weight (g)		Corm yield (g m^{-2})	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Nutrition program (NP)	*	*	**	**	**	**	**	**
NP0 (control)	143.4^{b}	278.1^{b}	2.20^{c}	2.79^{d}	3.37^{b}	4.11^{c}	533.8^{c}	1239.3^{d}
NP1	160.4^{a}	314.8^{ab}	2.77^{b}	2.92^{c}	3.97^{b}	5.37^{b}	580.1^{bc}	1310.5^{c}
NP2	157.0^{ab}	319.6^{a}	3.08^{b}	3.21^{b}	4.97^{a}	6.65^{a}	599.5^{b}	1441.5^{b}
NP3	163.4^{a}	312.1^{ab}	3.74^{a}	4.27^{a}	5.42^{a}	6.86^{a}	639.7^{a}	1565.4^{a}
Corm weight (CW)	NS	**	**	**	**	**	**	**
CW1		282.2^{b}	2.30^{c}	2.67^{c}	3.48^{c}	4.62^{c}	549.6^{c}	1298.5^{c}
CW2		313.6^{a}	2.95^{b}	3.20^{b}	4.46^{b}	5.75^{b}	597.2^{b}	1392.5^{b}
CW3		322.7^{a}	3.60^{a}	3.72^{a}	5.35^{a}	6.87^{a}	632.9^{a}	1476.5^{a}
NP×CW	NS	NS	*	**	*	*	*	*
NP0CW1			1.63^{e}	1.61^{h}	2.78^{h}	3.37^{f}	509.3^{f}	1156.2^{h}
NP0CW2			2.34^{de}	2.53^{g}	3.57^{fgh}	4.23^{ef}	554.3^{de}	1256.4^{g}
NP0CW3			2.64^{cd}	2.89^{ef}	3.76^{efgh}	4.72^{e}	597.6^{de}	1305.2^{f}
NP1CW1			2.38^{d}	2.65^{fg}	2.91^{gh}	4.63^{e}	533.9^{ef}	1219.1^{g}
NP1CW2			2.85^{cd}	2.99^{ef}	3.96^{ef}	5.34^{de}	599.8^{cd}	1307.5^{f}
NP2CW3			3.11^{b}	3.13^{de}	5.04^{bcd}	6.14^{cd}	606.5^{cd}	1405.0^{d}
NP2CW1			2.65^{cd}	3.71^{c}	4.35^{def}	5.24^{de}	568.8^{de}	1373.0^{e}
NP2CW2			3.05^{b}	3.13^{de}	4.68^{cde}	6.95^{bc}	611.3^{bc}	1466.6^{cd}
NP2CW3			3.57^{b}	3.71^{c}	5.89^{ab}	7.78^{b}	618.5^{bc}	1484.9^{b}
NP3CW1			2.56^{cd}	3.48^{cd}	3.89^{efg}	5.26^{de}	586.4^{cd}	1445.7^{cd}
NP3CW2			3.58^{b}	4.16^{b}	5.65^{bc}	6.51^{c}	623.5^{b}	1539.6^{b}
NP3CW3			5.09^{a}	5.15^{a}	6.73^{a}	8.82^{a}	709.3^{a}	1710.9^{a}
C.V (%)			5.67	6.75	3.42	2.71	10.35	8.16

* and **: Significant at $p<0.05$ and $p<0.01$, respectively. NS: Non-significant according to the LSD test.
Means within each column with same letters are not significantly different by LSD test ($p<0.05$).
NP0 to NP3 indicate nutrition programs. CW1 to CW3 indicate maternal corm weights.

Stigma and corm water productivity

Considering water shortage and poor soils in dry areas such as the experiment area where saffron occupies a major proportion of the land under cultivation of crops, one of the effective approaches for water conservation is the implementation of a suitable nutrition program for saffron growing. Increasing the saffron water use efficiency can play a significant role in the sustainable production of saffron (Koocheki & Seyyedi, 2020). The dry stigma water productivity (DSWP) significantly responded to the experimental treatments. Among the nutrition program treatments, the NP3 treatment by achieving the values of 0.885 and 1.942 g m^{-3} for the first and second year of the experiment, respectively, had the highest effect on the improvement of this index. The NP1 treatment in the first year (0.721 g m^{-3}) and the NP2 treatment in the second year (1.720 g m^{-3}) were in second place in terms of the effect on increasing DSWP (Table 6). Numerous researches revealed the significant effects of integrated nutrient management by organic, inorganic, and biological fertilizers on the WP of crops (Singh et al., 2019; Faloye et al., 2019; Midya et al., 2021). The DSWP increased as a result of planting maternal corms with more weight. The CW3 treatment, by obtaining the values of 0.754 and 1.680 g m^{-3} for the first and second year of the experiment, respectively, showed the highest DSWP. The CW2 treatment with 0.718 and 1.390 g m^{-3}, respectively, was in the next place (Table 6). Koocheki and Seyyedi (2020) found that farms with larger corms had more water use efficiency compared to smaller corms. They also stated that farms that received manure had higher water use efficiency compared to farms that were fertilized with chemical fertilizers.

The interaction effect of the experimental factors on the DSWP in the second year of the experiment was significant. The NP3CW3 treatment and, after it, the NP2CW3 treatment (2.260 and 1.971 g m^{-3}, respectively) caused the highest increase in the DSWP, while the lowest value (0.640 g m^{-3}) was observed in the NP0CW1 treatment (Table 6). The results of this research show that the integrated nutrition of saffron through the improvement of soil properties and the nutrient availability, mobility in soil and dynamics (Midya et al., 2021) and in overall improvement of the plant's growth environment has provided the conditions that the physiological processes of the plant done in a better manner that finally improved the vegetative and reproductive growth of the plant.

Investigating the response of corm water productivity (CWP) to different nutrition programs and different corm weight groups showed a significant variation of this index in response to the experimental treatments. As shown in Table 6, there was a significant difference among the nutrition treatments in terms of the effect on the CWP, so the highest value in the first and second years (2.10 and 4.45 kg m^{-3}, respectively) belonged to the NP3 treatment. The NP2 treatment, with values of 1.97 and 4.08 kg m^{-3}, respectively, and the NP1 treatment, with values of 1.90 and 3.77 kg m^{-3}, respectively, were ranked in the second and third place. The lowest value (1.81 and 3.65 kg m^{-3}, respectively) belonged to the control. Because of the limitation in arable lands and water resources, especially in arid and semi-arid regions, development of the agricultural sector will be possible only by increasing the resource use efficiency with minimal harmful effects on the agroecosystem through the use of modern and adaptable technologies (Amirnia et al., 2014). Soil fertility management by improving soil physicochemical and biological properties and enhancing quantitative and qualitative yields of crops plays an essential role in improving crop water productivity (Rockström et al., 2010).

Planting corms with more weight resulted in higher CWP, so the CW3 treatment had the highest value (2.07 and 4.18 kg m^{-3} in the first and second years of the experiment, respectively). The CW2 treatment ranked next with values of 1.96 and 3.99 kg m^{-3}, respectively, while the lowest values (1.80 and 3.67 kg m^{-3}, respectively) belonged to the

CW1 treatment (Table 6). The mean comparison of interaction effects showed that the NP3CW3 treatment, with values of 2.33 and 4.86 kg m^{-3} in the first and second year of the experiment, respectively, caused the highest increase in the CWP. The NP3CW2 and NP2CW3 treatments with values of 2.04 and 2.02 kg m^{-3} in the first year and 4.37 and 4.21 kg m^{-3} in the second year, respectively, ranked in the next place. The lowest values (1.67 and 3.25 kg m^{-3} in the first and second year, respectively) belonged to the NP0CW1 treatment (Table 6).

Table 6. Mean comparison for the dry stigma and corm water productivity as affected by nutrition programs and maternal corm weight.

Treatments	Dry stigma WP (g m^{-3})		Corm WP (kg m^{-3})	
	2016-17	2017-18	2016-17	2017-18
Nutrition program (NP)	**	**	**	**
NP0 (control)	0.557^{c}	0.850^{d}	1.81^{d}	3.65^{d}
NP1	0.721^{b}	1.053^{c}	1.90^{c}	3.77^{c}
NP2	0.656^{bc}	1.720^{b}	1.97^{b}	4.08^{b}
NP3	0.885^{a}	1.942^{a}	2.10^{a}	4.45^{a}
Corm weight (CW)	**	**	**	**
CW1	0.669^{c}	1.101^{c}	1.80^{c}	3.67^{c}
CW2	0.718^{b}	1.391^{b}	1.96^{b}	3.99^{b}
CW3	0.754^{a}	1.681^{a}	2.07^{a}	4.18^{a}
NP×CW	NS	**	*	**
NP0CW1		0.640^{h}	1.67^{c}	3.25^{b}
NP0CW2		0.810^{gh}	1.81^{bc}	3.54^{b}
NP0CW3		1.101^{ef}	1.95^{b}	3.69^{ab}
NP1CW1		0.780^{gh}	1.75^{bc}	3.43^{b}
NP1CW2		980^{gf}	1.97^{b}	3.89^{ab}
NP2CW3		1.391^{de}	1.99^{ab}	3.97^{ab}
NP2CW1		1.333^{de}	1.86^{b}	3.88^{ab}
NP2CW2		1.855^{bc}	2.00^{ab}	4.15^{ab}
NP2CW3		1.971^{b}	2.02^{ab}	4.21^{ab}
NP3CW1		1.652^{c}	1.92^{b}	4.09^{ab}
NP3CW2		1.913^{b}	2.04^{ab}	4.37^{ab}
NP3CW3		2.261^{a}	2.33^{a}	4.86^{a}
C.V (%)	11.14	6.50	10.05	7.94

* and **: Significant at p<0.05 and p<0.01, respectively. NS: Non-significant according to the LSD test. Means within each column with same letters are not significantly different by LSD test (p<0.05). NP0 to NP3 indicate nutrition programs. CW1 to CW3 indicate maternal corm weights.

CONCLUSION

The results of our research indicate a highly significant response of saffron to all types of nutrition systems. Based on the obtained results, the best nutrition program to improve the saffron flower indices (flower number, fresh and dry flower yield, fresh and dry stigma yield) and corm indices except for corm number (corm diameter, corm weight, and corm yield) was the NP3 treatment, in which the integrated nutrition system included various chemical and organic fertilizers in different forms was applied. Furthermore, the NP2 treatment (mineral fertilizers containing macro- and micronutrients and humic acid) was associated with the second-highest values of most of the mentioned saffron traits. The NP3 treatment led to the highest dry stigma and corm water productivity, significantly followed by the NP2 treatment. Additionally, the research results indicate the highly significant effects of maternal corm weight on the flower and corm properties of saffron. Planting corms with a higher weight group resulted in the improvement of all studied traits of saffron so the highest values were obtained as a result of planting corms with a weight group of 12-16 g, while the lowest values were obtained due to planting corms with a weight group of 4-8 g. Mean comparisons of the nutrition system and maternal corm weight interactions revealed that the best treatment for improving the saffron studied traits was the NP3CW3 treatment.

Conflict of interest

The authors have no conflict of interest to report.

Acknowledgment

The authors acknowledge the financial support and provide equipment for this research by University of Torbat-Heydariyeh, Torbat-Heydariyeh, Iran.

REFERENCES

Abdel-Raouf, N., Al-Homaidan, A.A., & Ibraheem, I.B.M. (2012). Agricultural importance of algae. *African Journal of Biotechnology*, *11*, 11648-11658. https://doi.org/10.5897/AJB11.3983

Adesina, I., Bhowmik, A., Sharma, H., & Shahbazi, A.A. (2020). Review on the current state of knowledge of growing conditions, agronomic soil health practices and utilities of hemp in the United States. *Agriculture*, *10*, 129. https://doi.org/10.3390/agriculture10040129

Agra, M.F., Freitas, P.F., & Barbosa-Filho, J.M. (2007). Synopsis of the plants known as medicinal and poisonous in northeast of Brazil. *Revista Brasileira de Farmacognosia-Brazilian Journal of Pharmacognosy*, *17*, 114-140. http://doi.org/10.1590/S0102-695X2007000100021

Ahmadi, A., & Nazari Alam, J. (2015). Effects of biological and chemical fertilizers on quantity yield of saffron (*Crocus sativus* L.) in different planting densities. *Journal of Saffron Research*, *3*(1), 51-63. https://doi.org/10.22077/jsr.2015.312

Alfa, M., Adie, D., Igboro, S., Oranusi, U., Dahunsi, S., & Akali, D. (2014). Assessment of biofertilizer quality and health implications of anaerobic digestion effluent of cow dung and chicken droppings. *Renewable Energy*, *63*, 681-686. https://doi.org/10.1016/j.renene.2013.09.049

Alie, B.A., Khan, M.H., Dar, N.A., Mir, G.H., Dar, S.A., Lone, A.A., Khan, A., Fayaz, U., Ali, M.T., & Bhat, A.H. (2023). Cost-effective saffron production system module for corm weight and planting density. *Journal of Innovative Agriculture*, *10*(2), 36-46. http://doi.org/10.37446/jinagri/rsa/10.2.2023.36-46

Alizadeh, M.B., Makarian, H., Ebadi, A., Eizadi Darbandi, E., & Gholami, A. (2018). Effect of biological and chemical fertilizers on stigma yield and quality of saffron (*Crocus sativus* L.) in climatic conditions of Ardabil. *Iranian Journal of Crop Sciences*, *20*(1), 16-29. http://dorl.net/dor/20.1001.1.15625540.1397.20.1.2.5

Al-Taey, D.K.A., Al-Shareefi, M.J.H., Mijwel, A.K., Al-Tawaha, A.R., & Al-Tawaha, A.R. (2019). The beneficial effects of bio-fertilizers combinations and humic acid on growth, yield parameters and nitrogen content of broccoli grown under drip irrigation system. *Bulgarian Journal of Agricultural Science*, *25*(5), 959-966.

Amirnia, R., Bayat, M., & Tajbakhsh, M. (2014). Effects of nano fertilizer application and mother corm weight on flowering at some saffron (*Crocus sativus* L.) ecotypes. *Turkish Journal of Field Crops*, *19*(2), 158-168. http://doi.org/10.17557/tjfc.46269

Ayoub, A.T. (1999). Fertilizers and the environment. *Nutrient Cycling in Agroecosystems*, *55*, 117-121. https://doi.org/10.1023/A:1009808118692

Azarmi-Atajan, F., & Sayyari-Zohan, M. H. (2022). Effect of phosphate solubilizing bacteria and triple superphosphate on the growth, physiological parameters and phosphorus uptake of pistachio seedlings. *Journal of Horticulture and Postharvest Research*, *5*(1), 69-78. https://doi.org/10.22077/jhpr.2022.4917.1260

Barker, A.V., & Pilbeam, D.J. (2007). *Handbook of Plant Nutrition*. New York, USA: Taylor and Francis Publication.

Ben El Caid, M., Salaka, L., El Merzougui, S., Lachguer, K., Lagram, K., El Mousadik, A., & Serghini, M.A. (2020). Multi-site evaluation of the productivity among saffron (*Crocus sativus* L.) for clonal selection purposes. *Journal of Applied Research on Medicinal and Aromatic Plants, 17*, 100248. https://doi.org/10.1016/j.jarmap.2020.100248

Besharati, H., & Saffari, H. (2022). The effectiveness of organic fertilizer from Poultry slaughterhouse waste on corn (*Zea maize*) and pistachio (*Pistacia vera*). *Applied Soil Research*, *10*(3), 78-89.

de Juan, J.A., Córcoles, H.L., Muñoz, R.M., & Picornell, M.R. (2009). Yield and yield components of saffron under different cropping systems. *Industrial Crops and Products*, *30*, 212-219. https://doi.org/10.1016/j.indcrop.2009.03.011

Douglas, M.H., Smallfield, B.M., Wallace, A.R., & Mc Gimpsey, J.A. (2014). Saffron (*Crocus sativus* L.): The effect of mother corm size on progeny multiplication, flower and stigma production. *Scientia Horticulturae, 166*, 50-58. https://doi.org/10.1016/j.scienta.2013.12.007

Ebrahimi, M., Pouyan, M., Shahi, T., Fallahi, H.R., Hoseini, S., Ragh Ara, H., & Branca, F. (2021). Effects of organic fertilisers and mother corm weight on yield, apocarotenoid concentration and accumulation of metal contaminants in saffron (*Crocus sativus* L.). *Biological Agriculture & Horticulture*, *38*(2), 73-93. https://doi.org/10.1080/01448765.2021.1987987

Ekta, N., Shailaja, P., Pant, S.C., Sandee, K., Pankaj, B., Bengia, M., & Nautiyal, B.P. (2017). Effect of organic manures and bio-fertilizers on growth, yield, quality and economics of broccoli (*Brassica Oleracea* l. Var. Italica Plenck) cv. Green head under high-hill conditions of Uttarakhand. *International Journal of Advanced Biological and Biomedical Research, 7*(1), 96-100.

El Grah, F. Z., Bennasser, S. M., El Ghazali, H., Ait Hammou, R., Harrouni, C., & Daoud, S. (2022). Characterization of the Moroccan saffron in relation to climate, soil, and water in its main production zones. *Journal of Horticulture and Postharvest Research*, *5*(2), 129-140. https://doi.org/10.22077/jhpr.2022.4487.1227

Esmaeilian, Y., Amiri, M.B., & Neamatollahi, E. (2022a). High density planting and manure affect flower yield, corm characteristics, and volatile compounds of saffron (*Crocus sativus* L.). *Industrial Crops and Products, 176*, 114363. https://doi.org/10.1016/j.indcrop.2021.114363

Esmaeilian, Y., Amiri, M.B., Tavassoli, A., Caballero-Calvo, A., & Rodrigo-Comino, J. (2022b). Replacing chemical fertilizers with organic and biological ones in transition to organic farming systems in saffron (*Crocus sativus*) cultivation. *Chemosphere, 307*, 135537. https://doi.org/10.1016/j.chemosphere.2022.135537

Fallahi, H.R., Aghhavani-Shajari, M., Feizi, H., & Sahabi, H. (2017). Mother corm weight and soil amendment improve the vegetative and reproductive growth of saffron (*Crocus sativus* L.). *Journal of Herbs, Spices & Medicinal Plants*, *22*(3), 110-114.

Fallahi, H. R., Abbasi Aval Bohlooli, S., Pahlavan, Z., Hosseini, S. M., Hosseini, S. A. H., & Ghohestani-Bojd, P. (2021). Saffron vegetative growth as affected by transplanting and direct corm planting under field conditions. *Journal of Horticulture and Postharvest Research*, *4*(Special Issue-Recent Advances in Saffron), 1-10. https://doi.org/10.22077/jhpr.2020.3635.1160

Faloye, O.T., Alatise, M.O., Ajayi, A.E., & Ewulo, B.S. (2019). Effects of biochar and inorganic fertiliser applications on growth, yield and water use efficiency of maize under deficit irrigation. *Agricultural Water Management, 217*, 165-178. https://doi.org/10.1016/j.agwat.2019.02.044

Feli, A., Maleki Farahani, S., & Besharati, H. (2018). The impact of chemical urea fertilizer and different organic and biofertilizers on both quantitative and qualitative yield and some soil properties in cultivation of saffron (*Crocus sativus* L.). *Crops Improvement*, *20*(2), 345-356. https://doi.org/10.22059/jci.2017.60472

Ghanbari, J., Khajoei-Nejad, G., van Ruth, S.M., & Aghighi, S. (2019). The possibility for improvement of flowering, corm properties, bioactive compounds, and antioxidant activity in saffron (*Crocus sativus* L.) by different nutritional regimes. *Industrial Crops and Products*, *135*, 301-310. https://doi.org/10.1016/j.indcrop.2019.04.064

Gismondi, A., Serio, M., Canuti, L., & Canini, A. (2012). Biochemical, antioxidant and antineoplastic properties of Italian saffron (*Crocus sativus* L.). *American Journal of Plant Sciences, 3*(11), 1573-1580. http://dx.doi.org/10.4236/ajps.2012.311190

Gresta, F., Lombardo, G.M., Siracusa, L., & Ruberto, G. (2008). Saffron, an alternative crop for sustainable agricultural systems. A review. *Agronomy for Sustainable Development*, *28*, 95-112.

Hosseinzadeh, S., Jafarikukhdan, A., Hosseini, A., & Armand, R. (2015). The application of medicinal plants in traditional and modern medicine: A review of *Thymus vulgaris. International Journal of Clinical Medicine, 6*, 635-642. https://doi.org/10.1051/agro:2007030

Janssen, B.H. (1993). Integrated nutrient management: the use of organic and mineral fertilizers. In *The role of plant nutrients for sustainable crop production in Sub-saharan Africa* (van Reuler, H., & Prins, W.H. eds). Wageningen, Netherlands: Ponsen and Looijen Publisher, 89-105.

Kawalekar, S.J. (2013). Role of biofertilizers and biopesticides for sustainable agriculture. *Journal of Bio Innovation*, *2*, 73-78.

Khorramdel, S., Eskandari Nasrabadi, S., & Mahmoodi, G. (2015). Evaluation of mother corm weights and foliar fertilizer levels on saffron (*Crocus sativus* L.) growth and yield components. *Journal of Applied Research on Medicinal and Aromatic Plants*, *2*(1), 9-14. https://doi.org/10.1016/j.jarmap.2015.01.002

Kirmani, N.A., Sofi, J.A., Chesti, M.H., Mir, I.A., Irshad, I., Fayaz, S., & Mir, W.J. (2022). Soil classification, nutrient management and land cover of saffron growing areas of Kashmir valley. In *The saffron genome. Compendium of plant genomes* (Vakhlu, J., Ambardar, S., Salami, S.A., & Kole, C. eds). Cham, Switzerland: Springer Publishing Company, 97-111.

Koocheki, A., & Seyyedi, S.M. (2015). Relationship between nitrogen and phosphorus use efficiency in saffron (*Crocus sativus* L.) as affected by mother corm size and fertilization. *Industrial Crops and Products*, *71*, 128-137. https://doi.org/10.1016/j.indcrop.2015.03.085

Koocheki, A., & Seyyedi, S.M. (2020). Nutrition management and farm's age affect saffron daughter corms behavior, nutrients uptake and economic water and fertilizer use efficiency: A large scale on-farm experiment in Torbat Heydarieh, Iran. *Communications in Soil Science and Plant Analysis*, *51*(9), 1161-1183. https://doi.org/10.1080/00103624.2020.1751191

Koocheki, A., Seyyedi, S.M., & Jamshid Eyni, M. (2014). Irrigation levels and dense planting affect flower yield and phosphorus concentration of saffron corms under semi-arid region of Mashhad, Northeast Iran. *Scientia Horticulturae*, *180*, 147-155. https://doi.org/10.1016/j.scienta.2014.10.031

Lage, M., & Cantrell, C.L. (2009). Quantification of saffron (*Crocus sativus* L.) metabolites crocins, picrocrocin and safranal for quality determination of the spice grown under different environmental Moroccan conditions. *Scientia Horticulturae*, *121*, 366-373. https://doi.org/10.1016/j.scienta.2009.02.017

Leone, S., Recinella, L., Chiavaroli, A., Orlando, G., Ferrante, C., Leporini, L., Brunetti, L., & Menghini, L. (2018). Phytotherapic use of the *Crocus sativus* L. (saffron) and its potential applications: A brief overview. *Phytotherapy Research*, *32*, 2364-2375. https://doi.org/10.1002/ptr.6181

Midya, A., Saren, B.K., Dey, J.K., Maitra, S., Praharaj, S., Gaikwad, D.J., Gaber, A., Alsanie, W.F., & Hossain, A. (2021). Crop establishment methods and integrated nutrient management improve: Part I. Crop performance, water productivity and profitability of rice (*Oryza sativa* L.) in the Lower Indo-Gangetic Plain, India. *Agronomy*, *11*, 1860. https://doi.org/10.3390/agronomy11091860

Nazari, N., & Feizi, H. (2021). Magnetic fields and titanium dioxide nanoparticles promote saffron performance: A greenhouse experiment. *Journal of Horticulture and Postharvest Research*, *4*(Special Issue-Recent Advances in Saffron), 33-42. https://doi.org/10.22077/jhpr.2021.3886.1182

Nourihoseini, S.M., Khorassani, R., Astaraei, A.R., Rezvani Moghadam, P., & Zabihi, H.R. (2016). Effect of different fertilizer resources and humic acid on some morphological criteria, yield and antioxidant activity of black zira seed (*Bunium persicum* Boiss.). *Applied Field Crops Research*, *29*(4), 87-104. https://doi.org/10.22092/aj.2017.110251.1150

Omidbaigi, R. (2000). *Approaches to Production and Processing of Medicinal Plants* (Vol. 2). Tehran, Iran: Tarahan Nashr Publications.

Rasouli, Z., Maleki Farahani, S., & Besharati, H. (2014). Saffron underground organs as affected by organic, biological, and chemical fertilizers. *Iranian Journal of Soil Research*, *28*(2), 295-312. https://doi.org/10.22092/ijsr.2014.120355

Renau-Morata, B., Nebauer, S.G., Sánchez, M., & Molina, R.V. (2012). Effect of corm size, water stress and cultivation conditions on photosynthesis and biomass partitioning during the vegetative growth of saffron (*Crocus sativus* L.). *Industrial Crops and Products, 39*, 40-46. https://doi.org/10.1016/j.indcrop.2012.02.009

Reynolds, J.F. (2017). Desertification. In *Encyclopedia of Biodiversity* (Levin, S.A. eds). Massachusetts, USA: Academic Press, 479-494.

Rockström, J., Karlberg, L., Wani, S.P., Barron, J., Hatibu, N., Oweis, T., Bruggeman, A., Farahani, J., & Qiang, Z. (2010). Managing water in rainfed agriculture-The need for a paradigm shift. *Agricultural Water Management, 97*, 543-550. https://doi.org/10.1016/j.agwat.2009.09.009

Roy, M., Karmakar, S., Debsarcar, A., Sen, P.K., & Mukherjee, J. (2013). Application of rural slaughterhouse waste as an organic fertilizer for pot cultivation of solanaceous vegetables in India. *International Journal of Recycling of Organic Waste in Agriculture*, *2*, 6. https://doi.org/10.1186/2251-7715-2-6

Saeidi Aboueshaghi, R., Omidi, H., & Bostani, A. (2022). Effect of chicken manure and chemical fertilizers on some morphological characteristics and flowers production and replacement corm of saffron (*Crocus sativus* L.) under irrigation regimes. *Saffron Agronomy and Technology*, *10*(1), 19-39. https://doi.org/10.22048/jsat.2022.300362.1436

Salehi, A., Fallah, S., Iranipour, R., & Abasi Surki, A. (2014). Effect of application time of integrated chemical fertilizer with cattle manure on the growth, yield and yield components of black cumin (*Nigella sativa* L.). *Journal of Agroecology*, *6*(3), 495-507. https://doi.org/10.22067/jag.v6i3.21290

Sarfraz, M., Khaliq, A., Tahir, M.M., Iqbal, M.A., Rehman, Z., & Shan, Q. (2023a). Saffron spice quality in response to integrated nutrient management under lesser Himalayan conditions of Rawalakot Azad Jammu & Kashmir. *Journal of Plant Nutrition*, *47*(1), 18-29. https://doi.org/10.1080/01904167.2023.2254322

Sarfraz, M., Khaliq, A., Tahir, M.M., & Sarwar, S. (2023b). Organo-mineral fertilization regimes trigger growth and stigma yield of temperate saffron (*Crocus sativus* L.). *Bragantia*, 82, e20220118. http://dx.doi.org/10.1590/1678-4499.20220118

SAS. (2008). Statistical Analysis System. Version 9.1, SAS Institute Inc., Cary, NC, USA.

Scherer, T.F., Seelig, B., & Franzen, D. (1996). *Soil, Water and Plant Characteristics Important to Irrigation.* Washington, DC, USA: NRCS Publications.

Selim, M.M. (2020). Introduction to the integrated nutrient management strategies and their contribution to yield and soil properties. *International Journal of Agronomy*, 1-14. https://doi.org/10.1155/2020/2821678

Singh, R., Singh, P., Singh, H., & Raghubanshi, A.S. (2019). Impact of sole and combined application of biochar, organic and chemical fertilizers on wheat crop yield and water productivity in a dry tropical agro-ecosystem. *Biochar, 1*, 229-235. https://doi.org/10.1007/s42773-019-00013-6

Siracusa, L., Gresta, F., & Ruberto, G. (2011). Saffron (*Crocus sativus* L.) apocarotenoids: A review of their biomolecular features and biological activity perspectives. In *Carotenoids: Properties, Effects and Diseases* (Yamaguchi, M. eds). UK: Nova Science Publishers, Inc, 1-33.

Tareen, N.M., Saeed-ur-Rehman, M.A., Shinwari, Z.K., & Bibi, T. (2016). Ethnomedicinal utilization of wild edible vegetables in district Harnai of Balochistan province, Pakistan. *Pakistan Journal of Botany, 48*(3): 1159-1171.

Tejada, M., Gómez, I., Fernández-Boy, E., & Díaz, M.J. (2014). Effects of sewage sludge and *Acacia dealbata* composts on soil biochemical and chemical properties. *Communications in Soil Science and Plant Analysis, 45*, 570-580. https://doi.org/10.1080/00103624.2013.874017

Temperini, O., Rea, R., Temperini, A., Colla, G., & Rouphael, Y. (2009). Evaluation of saffron (*Crocus sativus* L.) production in Italy: Effects of the age of saffron fields and plant density. *Journal of Food, Agriculture and Environment, 7*, 19-23.

Turhan, H., Kahriman, F., Egesel, C.O., & Gul, M.K. (2007). The effects of different growing media on flowering and corm formation of saffron (*Crocus sativus* L.). *African Journal of Biotechnology*, *6*(20), 2328-2332. https://doi.org/10.5897/AJB2007.000-2365