Agronomy Research **20**(X), xxx–ccc, 2022
https://doi.org/10.15159/AR.22.082

Effect of fertilizers on growth and productivity of saffron: a review

W. Hourani[1,2*]

[1]Lebanese University, Faculty of Agriculture Engineering and Veterinary Medicine, Plant production department, Beirut, Lebanon
[2]University of Forestry, Department of Agronomy, 10 Kliment Ohridski blvd, BG1797 Sofia, Bulgaria
[*]Correspondence: wissam.hourani@st.ul.edu.lb

Received: October 21st, 2022; Accepted: December 13th, 2022; Published: December 21st, 2022

Abstract. Saffron management involves a systematic approach to nutrient management. Controlling the amount, form, combinations and timing of nutrients delivered to plants is a pre-requisite for getting optimum yield and quality potential of saffron. Therefore, nutrient use efficiency and integrated nutrient management is a crucial tool for balanced fertilization and sustainable crop production. The impact and the need of organic and inorganic fertilization for saffron growth are discussed along with the possibilities of increasing qualitative and quantitative parameters by the integration of multiple fertilizers. The goal of this review is to give an overview of saffron nutrition management in order to maximize saffron growth and yield.

Key words: fertilization, saffron, stigma yield, nutrient management, organoleptic properties.

INTRODUCTION

Saffron (*Crocus sativus*) is a flowering plant of the genus Crocus in the family Iridaceae. It is one of the most valuable agricultural and medicinal plants that for centuries has been cultivated in Iran, India, and southern Europe (Menia et al., 2018). Saffron as the most expensive agricultural and medicinal plant has a unique status among industrial and export products, and important for producing employment opportunities (Golmohammadi, 2014) Saffron spice is made from the filaments that grow inside the flower. Saffron contains over 100 biologically active compounds, the most important of which are crocin, crocetin, picrocrocin, and safranal (Singletary, 2020).

A variety of factors affect saffron cultivation, including climate, crop density, irrigation, soil fertility, agricultural practices, and saffron type (Al Madini et al., 2019; Rezvani-Moghaddam, 2020). In addition, the main restrictions to saffron production are the fragmented and small land holdings in the nations where it is traditionally grown, low production and productivity levels, high labor costs, inconsistent climatic conditions, lack of scientific cultivation practices, and most importantly, to lack of awareness and interest on the appropriate choice and doses of manures and fertilizers among the saffron growers (Gresta et al., 2009). Thus, a balanced and timely supply of fertilizer is a pre-requisite for getting optimum yield and quality potential of saffron (Ghanbari & Khajoei-Nejad, 2022). Despite the low fertilizer requirement of saffron, studies confirmed that most changes of saffron flower yield depend on soil variables as affected by fertilizers and soil amendments (Temperini et al., 2009; Nehvi et al., 2010).

Soil fertility management is a proper strategy for increasing soil organic matter, strengthening microbial communities, preserving biodiversity, enhancing agricultural input efficiency, and eventually improving plant quantitative and qualitative yields (Koocheki et al., 2015; Rasouli et al., 2015). To attain this goal, the fertilization management program should be designed to increase nutrient use efficiency (Chen & Liao, 2017). Optimal nutrient delivery (Chen & Liao, 2017), controlled-release fertilizers (Vejan et al., 2021), integrated fertilization management (Alley & Vanlauwe, 2009), the use of organic nutrient resources, and beneficial symbiotic microorganisms with plant roots are all examples of methods that helps achieving nutrient use efficiency (Ghanbari & Khajoei-Nejad, 2021).

Chemical fertilizers are the most often used fertilizers in saffron fields, and their excess can jeopardize farmed soil and water quality, and reduce the yield of saffron (Dourandish et al., 2019). As a result, organic and biological fertilizers have attracted more interest for being more safe, low-cost, and have fewer negative environmental effects (Ebrahimi et al., 2022).

Organic fertilizers, such as soil amendments or surface mulches, and ecological fertility approaches, such as microbial inoculation and humic acid can increase agricultural productivity while preserving the environment (Shajari et al., 2022). Organic amendments have also been regarded as crucial means of improving plant nutritional status and soil properties, which can help to ensure long-term sustainability and positive economic returns in the fields (Chen et al., 2018). Organic fertilizers show compatibility with perennial crops, including saffron, and are natural and safe products that can be suitable for agricultural sustainability. The benefits of organic fertilizers on soil health, such as improved soil carbon sequestration, balanced pH, higher cation-anion retention, and micronutrient availability, have become increasingly apparent as compared to inorganic fertilizers, especially in the field of saffron cultivation (Singh et al., 2011).

Compost, animal manures, and vermicompost, as well as their integrated application, promote higher saffron growth, yield, and nutrient use efficiency, and improve soil properties and nutrient status (Cavagnaro, 2015; Koocheki & Seyyedi, 2015; Guo et al., 2016). It is proved that encapsulating fertilizers in nanoparticles increases nutrients uptake and reduces macro and micro nutrient deficiency (Chhipa, 2017; Shukla et al., 2019). Nanofertilizers have a greater capacity for absorption and are preferred over regular fertilizers (Solanki et al., 2015; Belal & El-Ramady, 2016; Khan & Rizvi, 2017). For a proper growth, plants require macronutrient in a fairly large proportion and micronutrients in relatively smaller amounts (Mandal, 2021).

The knowledge of the optimum saffron fertilization to improve yield and quality is lacking and requires comprehensive researches to reach a reliable long-term strategy to address the current issues. Considering the above facts, this review was undertaken to provide knowledge and better understanding of saffron fertilization requirement and to support the fertilizer management and development strategies based on available scientific findings. The reported information will help to predict the effective fertilizer requirement to improve saffron production.

Chemical fertilizers

Nitrogen (N). Nitrogen is one of the most important elements to increase saffron flowers and corm yield per plant and unit area. Nitrogen is known as a moving element and can be transferred from the aerial to t underground plant parts during growth, and especially at the end of each growing season (Koocheki & Seyyedi, 2015). Nitrogen fertilization increases nitrogen levels in saffron leaves, contributing in the formation of more chlorophyll molecules and higher photosynthetic activity, resulting in enhanced vegetative growth and biomass. Furthermore, the amount of material transported to underground organs and roots is determined by the photosynthetic level of saffron plant leaves, which increase the formation of daughter corms (Chaji et al., 2013). Nitrogen's ability to speed up plant growth resulted in larger flowers and heavier stigmas, but with lower percentages of safranal, crocin, and picrocrocin, reducing the stigma's flavor because the growth rate may be faster than the rate and amount of essential oil production by the plant, reducing its concentration in the stigma (Heydari et al., 2014).

Several studies discussed the effect of different nitrogen fertilizers on the growth and production of saffron. According to Kirmani et al. (2014), adding nitrogen at 90 kg ha^{-1} increases saffron yield by 57.57% and corm output by 79.62% over control. Omidi et al. (2009) conducted a study to determine the effects of nitrogen chemical and bio-fertilizer on quantitative yield and some quality components of saffron and found that using 150 kg ha^{-1} of urea or a mixture of 2.5 L ha^{-1} bio-fertilizer as Nitroxin (containing Azospirillum and Azotobacter) + 75 kg ha^{-1} urea resulted in the highest yield of stigma and style, and the highest crocine content. Also, adding 50 kg ha^{-1} of chemical nitrogen fertilizer to a biofertilizer containing plant growth promoting rhizobacteria, like Pseudomonas and Bacillus maximized saffron output and quality (Heydari et al., 2014).

Urea has shown to increase fresh and dry weight of corm and leaf, as well as the number of daughter corms (Chaji et al., 2013; Koocheki & Seyyedi, 2015). Further, the combined application of 10 t ha^{-1} vermicompost and 50 kg ha^{-1} urea nitrogen fertilizer significantly increased yields and enhanced soil characteristics. In fact, stigma dry yield, soil nitrogen content, soil organic matter, and available soil phosphorus increased by 42.6, 66.67, 68.39, and 43.75%, respectively, compared to the control (Feli et al., 2018).

Nitrogen fertilizer combined with manure is recommended for better saffron quality; compared to cow manure treatment, urea application increased safranal, crocin, and picrocrocin concentrations by 6%, 3% and 5%, respectively, while the former increased saffron yield by 20% in comparison to the latter (Abbasi & Sepaskhah, 2022).

Phosphorus (P). As the second most important element in plant nutrition, phosphorus plays a critical role in many physiological and biochemical activities in plants and its availability is one of the most effective variables in increasing saffron yield and quality (Fageria et al., 2013). Phosphorus promotes the synthesis of organic substance in leaves and their transport to the saffron corm, which aids in reproductive growth and boosts saffron output (Chaji et al., 2013; Koocheki et al., 2014). Studies have demonstrated that essential oils, such as phytolexins and safranal, are in dire need of phosphorus-containing compounds (Oftadeh et al., 2018).

The use of phosphorus fertilizer in various forms improved saffron corms' quality, vegetative characteristics, and increased stigma yield (Amirian & Kargar, 2016). In particular, it is shown that the use of 35 kg ha^{-1} of phosphorus increased the fresh weight of saffron corms and leaves, but decreased the number of corms (Chaji et al., 2013).

Also, the use of super phosphate (40 kg ha^{-1}) lead to early flowering (Amiri, 2008) and the application of Bio super phosphate increased leaf length (Alipoor Miandehi et al., 2014).

Potassium (K). Potassium is the second most important nutritional element for the growth and development of spice crops, and is frequently referred to as a quality component in crop production, as it enhances the usage of nitrogen and protein production, as well as size, weight, oil content, and color (Jiku et al., 2020; Fatematuzzohora & Karim, 2020). In plants like saffron, potassium is used as a flowering stimulator and is an important nutritional supply during the reproductive growth stage (Jabbari et al., 2017; Khayyat et el., 2018). Potassium fertilizer can also reduce the deleterious effects of salinity stress on saffron plant biomass formation in the roots and shoots, resulting in a higher yield in saline soil (Avarseji et al., 2013; Shayganfar et al., 2021). Foliar application of potassium at the rate of 3 L ha^{-1} increases leaf length, Leaf area index (LAI), stigma dry weight, crocin, picrocrocin and Safranal content (Akbarian et al., 2012). The application of 20 kg ha^{-1} of potassium in form of K_2SO_4 had the highest saffron dry stigma yield when compared to control and potassium in form of KCl (Zabihi & Feizi, 2014). The application of 200 kg ha^{-1} potassium sulfate led to increase in flower number and weight (5.5 and % 5.6 respectively), and stigma fresh and dry weights (by 10 and 8.5 % respectively) (Akrami et al., 2015). Research on the use of 200 kg ha^{-1} of sulfur fertilizer and 100 kg ha^{-1} of potassium sulfate increased 90% the stigma dry weight (476 g ha^{-1}) in comparison to control (250 g ha^{-1}) (Basatpour et al., 2022).

NPK. Choosing the right NPK fertilizer ratio, form, and placement is able to supply all of the nutrients needed by the saffron simultaneously, which is more effective than applying independent nitrogen, phosphorus and potassium. Foliar spraying of different NPK fertilizers improved flowering rate, flower yield, and stigma yield of saffron due to increasing in production assimilates and their translocation to corm and below ground organs (Mollafilabi & Khorramdel, 2016) (Table 1).

Foliar application of NPK fertilizer; Phosamco™4 combined with cow manure increased the leaf appearance rate (by 6 leaves per day), flower emergence rate (by 9.5 flowers per day), maximum fresh weight of flower (by 42.5 g m^{-2}), and stigma dry weight (by 0.4 g m^{-2}) compared to control (Mollafilabi & Khorramdel, 2016). Application of NPK fertilizer (60-30-60 kg ha^{-1}) increased stigma dry weight by 146% compared to control (1.16 g m^{-2} and 0.47 g m^{-2} respectively) (Shahriary et al., 2018).

Flower fresh weight, stigma dry weight, and daughter corms number obtained from 5–10 g mother corms increased following foliar application of Dalfard 15® (a commercialized saffron fertilizer with 12% N from Urea and Nitrate sources, 8% P, 4% K and also Zn, Cu, Mg, Fe, chelates) by 16.44 g m^{-2}, 0.24 g m^{-2}, and 142% respectively compared to control (Khorramdel et al., 2015). In comparison to Nitroxin biofertilizer, Dalfard 15® was able to increase saffron flower number per unit area, flower dry weight, and stigma yield by nearly three fold (Koocheki et al., 2009), while it increased corm weight and number by 40 and 72% over the control, with comparable results obtained from fertilization using Manure 40 t ha^{-1} + vermiwash + effective microorganisms (Madahi et al., 2017).

Table 1. Effects of chemical fertilizers on growth and quality characteristics of saffron

Fertilizers	Dose of application	Soil type	DSY	FN	RCN	RCW	Source
Urea	150 kg ha^{-1}	Clay loam	+150%	-	-	NS	Omidi et al., 2009
	90 kg ha^{-1}	Clay loam	+49%	-	+90%	-	Kirmani
	45 kg ha^{-1}		+37%	-	+19%	-	et al., 2014
Urea foliar application	7 kg ha^{-1}	Sandy loam	+41%	+18%	+28%	+42%	Azizi et al., 2020
Triple superphosphate	35 kg ha^{-1}	Silt loam	-	-	-60%	+50%	Chaji et al., 2013
Super phosphate	40 kg ha^{-1}	Sandy Loam	+17%	-	-	-	Amiri, 2008
Ammonium phosphate	120 kg ha^{-1}	-	+40%	NS	-	NS	Amirian & Kargar, 2016
Potassium sulfate	200 kg ha^{-1}	Loam	NS	NS	-	-	Akrami, 2015
	100 kg ha^{-1}		NS	NS	-	-	
Foliar application of potassium	3 lit ha^{-1}	-	+15%	-	-	-	Akbarian, 2012
Potassium sulfate	20 kg ha^{-1} concentration	Loam	+134%	-	-	-	Zabihi & Feizi, 2014
Phosamco™4 foliar NPK	7 mg kg^{-1} concentration	Silt loam	+108%	+110%	-	+24%	Mollafilabi & Khorramdel, 2016
Dalfard 15® foliar spraying	15% concentration	Silt loam	+200%	+138%	+142%	108%	Khorramdel et al., 2015
FerTrix foliar fertilizer	2 L ha^{-1}	Sandy Loam	+34%	+61%	-	-	Emami et al., 2018

Values shown are percentage increase or decrease when compared to control; +: increased; -: decreased; NS: No significant difference according to the study; DSY: Dry stigma yield; FN: Flower number; RCN: Replacement corm number; RCW: Replacement corm weight;

Foliar application of FerTrix foliar fertilizer (NPK 20-20-20 fertilizer at 2 L ha^{-1}) combined with amino acids (0.5 L ha^{-1}) improved flower number by 85% and stigma yield by 46% compared to control (Emami et al., 2018). Integration of NPK fertilizer (50 kg ha^{-1} urea), triple superphosphate fertilizer (40 kg ha^{-1}), and potassium sulfate (50 kg ha^{-1}) with combined biofertilizer (A. Sp., *P. aeruginosus* and *B. subtilis*) increased stigma dry yield (by 57%), and contents of picocrocin (by 44%), safranal (62%), and crocin (by 47%) in comparison with control (Aalizadeh et al., 2018).

Humic acid

The beneficial impact of humic acid on plant growth are attributed to a variety of variables, including greater water and nutrient uptake, increased nutrient availability, better root system development, higher chlorophyll content, and improvements in the plant's enzyme activity (Barea et al., 2005; Sabzevari et al., 2010). Humic acid content was found to have a good influence on the quantity of saffron flowers and to improve saffron yield and quality (Osmani Roudi et al., 2015; Mollafilabi & Khorramdel, 2016).

In the study of Ahmadi et al. (2017), picrocin content was influenced in response to soil application of humic acid recording the highest value (40.60%) with 15 kg ha^{-1} humic acid applied. The highest safranal (20.1%) and crocin (55.57%) were obtained in plants treated with 10 kg ha^{-1} humic acid. Soil application of humic acid with 10 L ha^{-1} improved corm weight (by 7%) (Rivandi et al., 2016), and with100 kg per h, it improved the number of flowers (by 38%), flower yield (by 39%) and stigma dry yield (by 183%) compared to control (Koocheki et al., 2015). Moreover, Ahmadi et al. (2018) reported the highest stigma dry (0.23 g m^{-2}) yield in plants treated with 10 kg ha^{-1} humic acid and the highest total weight of corms (23.09 g per plant) with 5 kg ha^{-1} humic acid. In a more recent study conducted by Gerdakaneh et al. (2020), it was found that the use of 20 kg ha^{-1} of solid humic acid and 3 L ha^{-1} of foliar humic acid has increased flower number (by 42.72%) and yield of dry stigma (by 78.61%) compared to control, while combining 10 kg ha^{-1} solid humic acid and 2 L ha^{-1} foliar humic acid has enhanced picrocrocin content (by 4.9%), and the combination 10 kg ha^{-1} solid humic acid and 3 L ha^{-1} foliar humic acid was the most successful in increasing Safranal content (by 4.4%). Armak et al. (2021) also obtained higher stigma dry weight following the application of Super Humic treatment (improvement by 86.49% relative to control).

Vermicompost

Organic compost boosts soil fauna and microbial biomass, as well as enzyme activity, resulting in higher organic matter mineralization and pest and disease resistance, both of which are critical in organic farming (Erhart & Hartl, 2010). The final products of composting technologies like vermicomposting are nutrient-dense and ecofriendly, with a wide range of agricultural applications as soil conditioners (Usmani et al., 2017). On saffron, the use of vermicompost proved to be more effective compared to chemical fertilizers as well as other types of organic fertilizers; For instance, the application of vermicompost (10.2 t ha^{-1}) proved to be more effective than mineral fertilizer (N 225 kg ha^{-1} + P 129.08 kg ha^{-1}) in increasing the number, weight, N and P contents of medium and large daughter corms per plant (Seyyedi et al., 2018).

Gholami et al. (2017) reported that applying 10 t ha^{-1} vermicompost yielded more corms than applying 10 t ha^{-1} of cow manure, and from spraying 10 L ha^{-1} Humaster Saffron fertilizer, and that applying vermicompost buried under planting corm rows yielded more corms than spreading vermicompost. Besides, vermicompost application (10 t ha^{-1}) produced higher flower number and stigma yield than other fertilizer treatments (hen manure 15 t ha^{-1}, humic acid 2 kg ha^{-1}, and chemical fertilizer containing 200 kg ha^{-1} urea and 140 kg ha^{-1} P and K) (Rezaie et al., 2019).

Animal manure

Animal-waste-derived organic fertilizer is a mainstay for sustainable agriculture since it improves soil fertility, microbial abundance, disease prevention, and economic issues. Furthermore, waste to fertilizer conversion is a low-energy requiring process that promotes circular bio-economy (Bhunia et al., 2021). In the long run, manure's small and constant release of nutrients enhances soil texture and structure while also meeting plant nutritional needs, resulting in better saffron yields on farms (Koocheki & Teimouri, 2014). In general, livestock manures have been shown to have a greater impact than chemical fertilizers on saffron yield and yield components (Alipoor et al., 2015).

Cow manure. The usage of livestock manure improved many soil fertility parameters (organic carbon, soil K, Mg, Ca, N-NH and CEC) and is one of the main causes of superior saffron quality and yield (Amiri, 2008; Jami-Alahmadi et al., 2009; Mohammad et al., 2012). For instance, in the study of Yarami & Sepaskhah (2015), the application of cow manure in 60 t ha^{-1} improved soil fertility and thus increased saffron yield by about 23%. It also mitigated the effect of saline irrigation on saffron. Further, cow manure applied in lower dose of 40 t ha^{-1} increased flower and total fresh weight of corm by 15.78 and 37.44 %, respectively (Osmani Roudi et al., 2015). In 30 t ha^{-1}, cow manure increased corms number and total corms weight per plant by 15 and 13%, respectively, compared with non-treated plants (Fallahi & Mahmoodi, 2018). According to Mollafilabi & Khorramdel (2016), the application of cow manure at a rate of 20 t ha^{-1} resulted in enhanced growth and yield of corm and flowers, and was able to double the stigma dry weight compered to control treatment.

When compared to chemical fertilizer (150 kg ha^{-1} urea + 75 kg ha^{-1} superphosphate), the use of 25 t ha^{-1} cow manure resulted in a greater improvement in total replacement corm yield, number, weight, and phosphorus content of replacement corms (Feizi et al., 2015; Koocheki et al., 2015a). The nitrogen (N) and phosphorus (P) use efficiency in saffron of composted cow manure treatment was found to be higher than that of chemical fertilizer (Koocheki & Seyyedi, 2015; Koocheki et al., 2015b). Moreover, cow manure applied in 20 t ha^{-1} induced higher fresh and dry stigma yield compared to foliar application of Delfard (NPK) in 7 kg ha^{-1} and floral Phosphorus in 2.5 kg ha^{-1} (Kianimanesh et al., 2021). Furthermore, improvements in stigma dry weight as a result of cow manure application at a rate of 40 t ha^{-1} reached 77.3, 71.7, and 58.9% increase respectively compared with non-treated plants, plants treated with humic acid, and plants subjected to Omic treatments (organic-mineral-based emulsion) (Ebrahimi et al., 2020).

The combination of cow manure (20 t ha^{-1}) and mycorrhizal fungus inoculation (*Glomus mosseae)* doubled flower number and yield, and enhanced organoleptic properties (picrocrocin and safranal contents) as well as total phenolic and total flavonoid contents in tepals (Ghanbari et al., 2019). The application of cow deep litter manure (20 t ha^{-1}) with combination of super phosphate at (40 kg ha^{-1}) and urea (50 kg ha^{-1}) resulted in highest yield (0.45 g m^{-2}) and maximum flower fresh weight (0.99 g), while, the lowest (0.24 g m^{-2}) and (0.50 g) with control, respectively (Amiri, 2009). Besides, combined effects of cow manure (20 t ha^{-1}) and urea (50 kg ha^{-1}) on saffron consisted of an optimization in flower fresh weight, stigma length, and yield (Mohammad et al., 2012).

Chicken manure. Aminifard & Gholizade (2018) investigated the effect of chicken manure application on saffron, and reported that a dose of 5 t ha^{-1} produced the maximum dry weight of stigma (increase by 0.32 g over the control). In drought conditions, the combined use of chicken manure and chemical fertilizer (ratio 3:1) improved saffron growth and yield, but the highest quality of saffron was obtained with a ratio (1:3); where chemical fertilizer share is higher (Aboueshaghi et al., 2022). Compared to a conventional chemical fertilizer (100 kg ha^{-1} urea + 80 kg ha^{-1} triple superphosphate), chicken manure applied in 5 t ha^{-1} provided significant improvement in many indicators, as follows: flowers number per m^2 (by 86.0), fresh flower weight (by 32.6 g m^{-2}), stigma dry weight (0.236 g m^{-2}), style dry weight (0.605 g m^{-2}), stigma harvest index (by 0.0071). In addition, chicken manure caused the greatest improvements in major studied characteristics of replacement corms (Shariatmadari et al., 2018).

Farmyard manure

Kirmani et al. (2014) found that applying farmyard manure at a rate of 90 kg ha^{-1} has increased saffron yield by 43.26% and corm output by 260.97% over the control. Over the course of three years, the application of Farmyard manure (FYM) at 350 kg ha^{-1} in combination with N:P:K at 30:20:15 kg ha^{-1} resulted in a maximum saffron yield with 91% improvement over control plots (Nehvi et al., 2010). The combination of 350 kg ha^{-1} FYM with Compound Liquid Fertilizer (12% N, 7% P2O5, K2O, Fe, Zn Chelates) at the rate 7 g per 1,000 m resulted in the maximum corm yield (1,047 g m^{-2}) (Nehvi et al., 2010).

Microbial inoculation

The use of biological fertilizers, which is one of the most successful management approaches for maintaining soil quality at the optimum level, is another novel method for providing the nutrients needed by the plant (Fallahi et al., 2009). Beneficial microorganisms have been used in agricultural activities for over 60 years, and helped enhancing plant resilience to different environmental challenges, such as drought, nutrients deficiency, and heavy metal toxicity (Wu et al., 2005).

In general, studies on the effect of microbial application on saffron have shown that rhizosphere bacteria act by stabilizing atmospheric nitrogen, increasing the availability of nutrients in the rhizosphere, increasing root contact and improving beneficial coexistence with host plants, and thus improving saffron growth and yield at different stages of the growing cycle (Rasool et al., 2021). Plant growth-promoting rhizobacteria (PGPR) release metabolites that directly stimulate growth, supporting the host plant by the ability to promote asymbiotic nitrogen fixation (Khan, 2005); produce phytohormones that promote plant growth (Marques et al., 2010); solubilize organic and inorganic phosphates (Alori et al., 2017) and has antagonistic activity against phytopathogenic microorganisms (Ren et al., 2020).

Azospirillum and Azotobacter. The bacteria in nitroxin biofertilizer (Azospirillum and Azotobacter) facilitated flower weight gain in saffron through an enhanced secretion of plant growth-regulating hormones, an improved development of saffron roots and aerial parts, a better nitrogen fixation and uptake by plant roots, and a more balanced uptake of essential nutrients and micronutrients required by the plant (Alipoor Miandehi et al., 2013).

In another study conducted by Pazoki et al. (2017), the same product (Nitroxin) increased vegetative traits and saffron dry yield (stigma + style weight) to 2.08 kg ha^{-1} compared to control (1.59 kg ha^{-1}) and significantly improved qualitative traits like Safranal, Picrocrocin, and Crocin. On the other hand, biofertilizer application in the form of viable strain of *Azotobacter* (5 kg ha^{-1}) has only positively influenced corm production, but its combined application with 90 kg of chemical nitrogen fertilizer has increased saffron yield (Kirmani et al., 2014). Besides, it was demonstrated that 0.2% Azotobacter-1 biofertilizer (containing *Azotobacter vinelandii*) is recommended to obtain higher production of saffron, and 1% Nitrokara (containing *Azorhizobium* *caulinodans*) to achieve higher content of active substances including antioxidants and total phenol (Parsa et al., 2018).

Pseudomonas putida and Pantoea agglomerans. One of the possible solutions needed to mitigate the problem of phosphorus deficiency is the use of phosphate-solubilizing bacteria to improve phosphorus uptake and reduce phosphorus fertilizer use. In this regard, *Pseudomonas putida* and *Pantoea agglomerans* are more efficient than chemical fertilizers at dissolving phosphorus from organic and inorganic substances (Aalizadeh et al., 2018). Farahani et al. (2014) found that using fertile phosphate biofertilizers with phosphorus-soluble bacteria helped to increase saffron yield by allowing organic chemicals and minerals to be absorbed more effectively. In addition, Parray et al. (2013) reported that the application of biofertilizers containing Pseudomonas bacteria encouraged the growth and enlargement of corms and increased stigma biomass.

The use of 100 g ha^{-1} of Phosphate Barvar2 (containing *Pseudomonas putida* strain P13 and *Pantoea agglomerans* strain P5) produced the highest saffron yield (improvement by 13.77%) compared to the application of 150 kg ha^{-1} of phosphorus as ammonium phosphate, and caused the highest picrocrocin content. In a similar study, 100 g ha^{-1} of Phosphate Barvar2 biofertilizer increased the corm number and flower dry weight (Bekhradiyaninasab et al., 2020). Further, a mixture of 50 g ha^{-1} of biophosphore (containing *Pseudomonas putida* strain P13 and *Pantoea agglomerans* strain P5) + 75 kg ha^{-1} chemical phosphorous as ammonium phosphate maximized safranal and crocin content (Naghdibadi et al., 2011). Additionally, the application of plant growth promoting bacteria (biofertilizer containing Pseudomonas and Bacillus) caused improvement in leaf length, leaf fresh and dry weight, chlorophyll b, total chlorophyll, carotenoids, zinc, and phosphorus concentrations (by 61.64%, 79.71%, 82.05%, 4.01%, 4.90%, 4.23%, 20.18% and 20.23% respectively compared to control) (Rasouli et al., 2013).

Mycorrhiza. Mycorrhizal colonization has been successfully implemented on saffron roots leading to significantly promoted mineral nutrient acquisition (Lone et al., 2016), as well as yield, quality, and volatile profile of saffron, particularly when integrated with fertilization (Ghanbari & Khajoei-Nejad, 2021).

For instance, the use of 10 g mycorrhiza (for every two corms with the same weight 7.5 ± 0.5 g) enhanced the stigmas dry yield and leaf dry weight by 46.21% and 137.5% respectively compared to control. Saffron roots were better colonized with mycorrhiza under organic nutritional treatments, as the treatment of 24 t ha^{-1} vermicompost and 10 g mycorrhiza fertilizer (for every two corms with the same weight 7.5 ± 0.5 g) increased saffron flower number in two consecutive years of study (Jami et al., 2020). Integration of arbuscular mycorrhizal (AM) fungus inoculation (*Funneliformis mosseae*) and different fertilizer types was reported to cause significant increases in leaf parameters, leaf nitrogen and phosphorus uptake, and leaf dry matter, yielding higher corm dry matter (Ghanbari & Khajoei-Nejad, 2022).

Integrated fertilizer application

The use of organic and inorganic fertilizers in the form of cow manure, vermicompost, Urea (nitrogen), diammonium phosphate (phosphorous) and Muriate of

Potash (potassium) (in the ratio of 90 N:60 P_2O_5:50 K_2O kg ha^{-1}) in combination with 10 t ha^{-1} FYM and 0.5 t ha^{-1} vermicompost recoded maximum number of flowers plot associated with maximum saffron yield plot showing an increase in saffron yield to the extent of 154.86% and corm yield by 150% over control (Naseer et al., 2012). Also, the integration of 90 kg ha^{-1} N was combined with 30 t ha^{-1} FYM has optimized saffron yield, while the application of 90 kg ha^{-1} N coupled with 60 t ha^{-1} FYM has maximized N, P, and K content in leaves (Sofi et al., 2013). Seaweed extracts (2 L ha^{-1}) proved to be effective in improving many saffron indicators, like stigma dry weight, flowers number, corm and leaves dry weights (Azizi et al., 2020).

Nano-fertilizers

Nanofertilizers have had different effects on many physiological characteristics of saffron like antioxidant enzymes, reducing and non-reducing sugars, photosynthetic pigments, total phenol content and relative water content of leaf (Rostami et al., 2019). For instance, the use of different nanofertilizers (iron: Fe, boron: B, manganese: Mn, potassium: K, and zinc: Zn) increased leaf protein and relative water content (Rostami et al., 2017). Moreover, Amirnia et al. (2014) reported a positive effect of Fe, P, and K nanofertilizers on saffron flowering and production traits; flower number, stigma length, fresh and dry stigma weights, fresh and dry flower weights, and dry stigma yield. Hashemabadi et al. (2020) reported that the use of nanofertilizers increased both the quantitative and qualitative yield of saffron by making the best nutrients available (Table 2).

Table 2. Effects of Nano fertilizers on growth and quality characteristics of saffron

Fertilizers	Soil type	Dose of application	DSY	FN	RCN	RCW	Source
Nano Zn	Silt loam	6 g L^{-1} concentration	+25%	+40.5%	-	-	Rostami et al., 2019
Nano Chelated Fe	Silt loam	10 kg ha^{-1}	+133%	+93%	+102%	+219%	Baghai & Maleki Farahani, 2013
Nano TiO2	-	2,000 ppm concentration	+15%	-	52%	-	Nazari & Feizi, 2021
Nano silver	Loam	50 ppm concentration	+44%	-	-	-	Mahmoodi et al., 2021
Nano silicon	Sandy loam	1.5 ppt concentration	+17%	+11%	+7%	NS	Khoshpeyk et al., 2022
Nano NPK[1]	Loam	5 mg L^{-1} concentration	+70%	+71%	-	-	Hashemabadi et al., 2020

Values shown are percentage increase or decrease when compared to control; +: increased; -: decreased; NS: No significant difference according to the study; DSY: Dry stigma yield; FN: Flower number; RCN: Replacement corm number; RCW: Replacement corm weight; [1]Results shown for the treatment Nano NPK was on the planting date of 5th of September.

Foliar spraying of Fe is one of the quickest ways to meet the plants need for iron (Malhotra et al., 2020). According to Azarpour et al. (2013) foliar spraying of nano iron fertilizers with 2 g L^{-1} resulted in the highest amount of fresh flower yield (173.3 kg ha^{-1}). Furthermore, the application of 10 kg ha^{-1} Nano Chelated iron fertilizer improved many vegetative and productive indicators; including dried stigma yield, flower fresh weight, flowers number, leaves number, leaves length, main corm diameter, and corm total weight (Baghai & Maleki Farahani, 2013; Maleki Farahani & Aghighi Shahverdi, 2015). The latter experiments also revealed that nano-iron was more effective than common iron chelate fertilizer; where 5 kg ha^{-1} of the first had the same effects on most saffron traits as 10 kg ha^{-1} of the second. Salariyan et al. (2021) study shows that application of nano fertilizer of Fe caused a significant increase of dry weight of stigma.

Foliar application of nano Zinc Oxide (6 g L^{-1}) and conventional Zinc Oxide (9 g L^{-1}) had significant effects on the saffron yield and number of flowers, and morpho-physiological characteristics of saffron (Rostami et al., 2019). Foliar application of Zn improves leaf traits, dry matter production, and antioxidant enzymes that have a direct and indirect effect on improvement of saffron yield (Akbarian et al., 2012).

CONCLUSION

When compared to other fertilizers, foliar NPK fertilizers was able to increase the dry stigma yield by two and three-fold. In addition, the application of Nano chelated Fe at a rate of 10 kg ha^{-1} increased dry stigma yield by 133%, while cow manure at a rate of 20 t ha^{-1} increased stigma dry weight by 100%. It is also shown that the vermicompost at a rate of 10 t ha^{-1}, and 10 kg ha^{-1} humic acid were the best rates of application for improving the quantitative and qualitative yield of saffron, but the use of any of these organic fertilizers in combination with biofertilizers (*Azotobacter*, *Pseudomonas aeruginus*, and *Bacillus subtilis*) has a greater effect on increasing the quantitative and qualitative yield of saffron. The use of livestock manure and vermicompost together had a synergistic effect on saffron bacterial fertilizer. Even though foliar application of NPK fertilizers as well as the nano Fe could obtain a higher yield increase, it is recommended to use organic fertilizers for improving soil formation and structure and creating more stable agriculture system. In other words, organic fertilizers increase saffron growth, flowering, and quality properties by improving soil granulation, increasing water storage capacity, improving soil nutrient exchange capacity, and generally creating a suitable environment for bacterial growth and multiplication. In addition to having good impacts on most of the examined traits, the use of bio and organic fertilizers can enable the viability of saffron ecological production while reducing the use of chemical fertilizers, and can be considered a step toward sustainable agriculture.

Further testing of the reviewed fertilizers combined or alone in other doses and timing of application is required to understand the optimal nutritional management for the saffron crop. In addition, long-term use of organic and biological fertilizers should be investigated further to achieve sustainable and productive stage that is suitable and ideal alternative to chemical fertilizers.

REFERENCES

Aalizadeh, M.B., Makarian, H., Ebadi, A., Darbandi, E.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.

Abbasi, M.R. & Sepaskhah, A.R. 2022. Evaluation of Saffron Yield Affected by Intercropping with Winter Wheat, Soil Fertilizers and Irrigation Regimes in a Semi-arid Region. *International Journal of Plant Production*, 1–19.

Aboueshaghi, R.S., Omidi, H. & Bostani, A. 2022. Assessment of changes in secondary metabolites and growth of saffron under organic fertilizers and drought. *Journal of Plant Nutrition*, 1–15.

Ahmadi, F., Aminifard, M.H., Khayat, M. & Samadzadeh, A. 2017. Effects of different humic acid levels and planting density on antioxidant activities and active ingredients of saffron (Crocus sativus L.). *Saffron agronomy and technology* **5**(1), 61–71.

Ahmadi, F., Aminifard, M.H., Khayyat, M. & Samadzade, A.R. 2018. Effects of humic acid and corm density on saffron yield and yield components in the second year. *Saffron agronomy and technology* **6**(2), 197–207.

Akbarian, M.M., Sharifabad, H.H., Noormohammadi, G.H. & Kojouri, F.D. 2012. The effect of potassium, zinc and iron foliar application on the production of saffron (*Crocus sativa*). *Annals of Biological Research* **3**(12), 5651–5658.

Akrami, M.R., Malakouti, M.J. & Keshavarz, P., 2015. Study of flower and stigma yield of saffron as affected by potassium and zinc fertilizers in Khorasan Razavi Province. *Journal of Saffron Research* **2**(1), 85–96.

Al Madini, A.M., Sassine, Y.N., El-Ganainy, S.M., Hourani, W. & Sebaaly, Z.E. 2019. Comparative study on phenology, yield and quality of iranian saffron cultivated in lebanon and iran. *Fresenius Environmental Bulletin* **28**(12A), 9655–9660.

Alipoor Miandehi, Z., Mahmodi, S., Behdani, M.A. & Sayyari, M.H. 2013. Effect of manure, bio-and chemical-fertilizers and corm size on saffron (*Crocus sativus* L.) yield and yield components. *Journal of Saffron Research* **1**(2), 73–84.

Alipoor Miandehi, Z., Mahmoodi, S., Behdani, M.A. & Sayyari, M.H. 2014. Effects of corm weight and application of fertilizer types on some growth characteristics and yield of saffron (*Crocus sativus* L.) under Mahvelat conditions. *Journal of Saffron Research* **2**(2), 97–112.

Alipoor, Z., Mahmoodi, S., Behdani, M.A. & Sayyari, M.H. 2015. Effect of Bio-, Manure and Chemical Fertilizers and Corm Weight on the Corm Characteristics of Saffron (*Crocus sativus*). *Plant products technology (agricultural research)* **15**(2), 13–24.

Alley, M.M. & Vanlauwe, B. 2009. The role of fertilizers in integrated plant nutrient management. In *International Fertilizer Industry Association*, 1st ed.; IFA: Paris, France; TSBF-CIAT: Nairobi, Kenya, 2009; ISBN 2952313946

Alori, E.T., Glick, B.R. & Babalola, O.O. 2017. Microbial phosphorus solubilization and its potential for use in sustainable agriculture. *Frontiers in microbiology* **8**, 971.

Aminifard, M.H. & Gholizade, Z. 2018. Impact of chicken manure on vegetative criteria and photosynthetic pigments of saffron (*Crocus sativus* L.). *Horticultural plant nutrition* **1**(1), 1–17.

Amiri, M. E. 2009. Comparison of animal Manures and Chemical Fertilizers on Saffron (*Crocus sativus* L.) cultivation. *UC Davis: Department of Plant Sciences*. Retrieved from *https://escholarship.org/uc/item/14d581t5*

Amiri, M.E. 2008. Impact of animal manures and chemical fertilizers on yield components of saffron (*Crocus sativus* L.). *American-Eurasian Journal of Agriculture and Environmental Science* **4**(3), 274–279.

Amirian, F. & Kargar, S.M.A. 2016. Evaluation of gibberellic acid, corm size and phosphoric fertilizer on yield and other traits of saffron (*Crocus sativus*) (Ghaen Ecotype). *Journal of Saffron Research* **4**(1), 134–148.

Amirnia, R., Bayat, M. & Tajbakhsh, M. 2014. Effects of nano fertilizer application and maternal corm weight on flowering at some saffron (*Crocus sativus* L.) ecotypes. *Turkish Journal of Field Crops* **19**(2), 158–168.

Armak, A.A., Feizi, H. & Alipanah, M. 2021. Influence of nitrogen, acid humic and nitrogen, phosphorus-soluble bacteria on saffron (*Crocus sativus* L.) corm reproduction and flower production of Torbat Heydarieh landrace. *Iranian Journal of Seed Science and Technology* **10**(2), 73–84.

Avarseji, Z., Kafi, M., Sabet Teimouri, M. & Orooji, K. 2013. Investigation of salinity stress and potassium levels on morphophysiological characteristics of saffron. *Journal of Plant Nutrition* **36**(2), 299–310.

Azarpour, E., Asghari, J. Bozorgi1, H.R. & Kamalpour, G. 2013. Foliar Spraying of Ascophyllum nodosum Extract, Methanol and Iron Fertilizers on Fresh Flower Cover yield of Saffron plant (*Crocus sativus* L.). *International Journal of Agriculture and Crop Sciences* **5**(17), 1854–1862.

Azizi, G., Musavi, S.G., Seghatoleslami, M.J. & Fazeli Rostampour, M. 2020. The Effect of Foliar application of seaweed Extract, Urea and micronutrient fertilizers on Performance and Its Components of saffron (*Crocus sativus* L.). *Journal of Saffron Research* **8**(1), 141–159.

Baghai, N. & Maleki Farahani, S. 2013. Comparison of Nano and micro Chelated iron fertilizers on quantitative yield and assimilates allocation of saffron (*Crocus sativus* L.). *Journal of Saffron Research* **1**(2), 156–169.

Barea, J.M., Pozo, M.J., Azcon, R. & Azcon-Aguilar, C. 2005. Microbial co-operation in the rhizosphere. *Journal of experimental botany* **56**(417), 1761–1778.

Basatpour, G., Kheirkhah, M. & Babaeian, M. 2022. Effect of Sulfur and Potassium Fertilizers on Yield and Yield Components of Saffron (*Crocus Sativus* L.) in Kermanshah. *Journal of Saffron Research* **9**(2), 242–228.

Bekhradiyaninasab, A., Balouchi, H., Movahhedi Dehnavi, M. & Sorooshzadeh, A. 2020. Effect of benzyl aminopurine, phosphate solubilizing bio-fertilizers and maternal corm weight on the qualitative indices of saffron (*Crocus sativus* L.) flowers and cormlets in Yasouj region. *Journal of Saffron Research* **8**(1), 99–113.

Belal, E.S. & El-Ramady, H. 2016. Nanoparticles in water, soils and agriculture. In *Nanoscience in food and agriculture* **2**, Springer, Cham, pp. 311–358.

Bhunia, S., Bhowmik, A., Mallick, R. & Mukherjee, J. 2021. Agronomic efficiency of animal-derived organic fertilizers and their effects on biology and fertility of soil: A review. *Agronomy* **11**(5), 823.

Cavagnaro, T.R. 2015. Biologically regulated nutrient supply systems: compost and arbuscular mycorrhizas—a review. *Advances in Agronomy* **129**, 293–321.

Chaji, N., Khorassani, R., Astaraei, A. & Lakzian, A. 2013. Effect of phosphorous and nitrogen on vegetative growth and production of daughter corms of saffron. *Journal of saffron research* **1**(1), 1–12.

Chen, L. & Liao, H. 2017. Engineering crop nutrient efficiency for sustainable agriculture. *Journal of Integrative Plant Biology* **59**(10), 710–735.

Chen, Y., Camps-Arbestain, M., Shen, Q., Singh, B. & Cayuela, M.L. 2018. The long-term role of organic amendments in building soil nutrient fertility: a meta-analysis and review. *Nutrient Cycling in Agroecosystems* **111**(2), 103–125.

Chhipa, H. 2017. Nanofertilizers and nanopesticides for agriculture. *Environmental chemistry letters* **15**(1), 15–22.

Dourandish, A., Ramezani, M. & Aminizadeh, M. 2019. Investigation of the effective factors on use of chemical fertilizers in saffron farms (Case study: Gonabad county). *Saffron agronomy and technology* **7**(3), 359–376.

Ebrahimi, M., Pouyan, M. & Mahdi Nezhad, M. 2020. Studying the possibility of replacing manure with other organic amendments in saffron (Crocus sativus L.) cultivation at different mother corm weights. *Saffron agronomy and technology* **8**(1), 37–57.

Ebrahimi, M., Pouyan, M., Shahi, T., Fallahi, H.R., Hoseini, S., Ragh Ara, H. & Branca, F. 2022. 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.

Emami, M., Armin, M. & Jamimoeini, M. 2018. The effect of foliar application time of organic and chemical fertilizers on yield and yield components of saffron. *Saffron agronomy and technology* **6**(2).

Erhart, E. & Hartl, W. 2010. Compost use in organic farming. In *Genetic engineering, biofertilisation, soil quality and organic farming.* Springer, Dordrecht, 311–345.

Fageria, N.K., Moreira, A. & Dos Santos, A.B. 2013. Phosphorus uptake and use efficiency in field crops. *Journal of plant nutrition* **36**(13), 2013–2022.

Fallahi, H.R. & Mahmoodi, S. 2018. Influence of organic and chemical fertilization on growth and flowering of saffron under two irrigation regimes. *Saffron agronomy and technology* **6**(2), 147–166.

Fallahi, J., Koocheki, A.R. & Rezvani Moghadam, P. 2009. Effects of biofertilizers on quantitative and qualitative yield of chamomile (Matricaria recutita) as a medicinal plant. *Iranian Journal of Field Crops Research* **7**(1), 127–135.

Farahani, S.M., Amini, S., Sharghi, Y. & Zahedi, H. 2014. Influence of vermicompost and bacterium of Bacillus and Pseudomonas on growth, yield and morphological traits of saffron. *Journal of Applied Science and Agriculture* **9**(3), 933–941.

Fatematuzzohora, S.S. & Karim, M.R. 2020. Effects of seedling age and potassium fertilizer on growth and yield of summer onion. *Asian Journal of Crop, Soil Science and Plant Nutrition* **4**(1), 134–140.

Feizi, H., Seyyedi, S.M. & Sahabi, H. 2015. Effect of corm planting density, organic and chemical fertilizers on formation and phosphorus uptake of saffron (Crocus sativus L.) replacement corms during phonological stages. *Saffron agronomy and technology* **2**(4), 289–301.

Feli, A., Maleki Farahani, S. & Besharati, H. 2018. The effect of urea fertilizer and different organic and bio-fertilizers on quantitative and qualitative yield and some soil properties in Saffron cultivation. *Journal of Crops Improvement* **20**(2), 345–356.

Gerdakaneh, M., Amini, E. & Khan Ahmadi, M. 2020. Effects of Soil and Foliar Spraying Application of Humic Acid on Qualitative and Quantitative Properties of Saffron. *Journal of Saffron Research* **8**(1), 71–84.

Ghanbari, J. & Khajoei-Nejad, G. 2021. Integrated nutrient management to improve some soil characteristics and biomass production of saffron. *Industrial Crops and Products* **166**, p. 113447.

Ghanbari, J. & Khajoei-Nejad, G. 2022. Relationships between growth indices, dry matter production, and nutrient use efficiency in saffron: Integrative effect of mycorrhizal inoculation and nutrient resources. *Journal of Plant Nutrition*, 1–19.

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.

Gholami, M., Kafi, M. & Khazaei, H.R. 2017. Study of the relations of sink and source in saffron by means of correlation coefficients under different irrigation and fertilization levels. *Saffron agronomy and technology* **5**(3), 195–210.

Golmohammadi, F. 2014. Saffron and its farming, economic importance, export, medicinal characteristics and various uses in South Khorasan Province-East of Iran. *International Journal of Farming and Allied Sciences* **3**(5), 566–596.

Gresta, F., Lombardo, G.M., Siracusa, L. & Ruberto, G. 2009. Saffron, an alternative crop for sustainable agricultural systems: a review. *Sustainable agriculture*, 355–376.

Guo, L., Wu, G., Li, Y., Li, C., Liu, W., Meng, J., Liu, H., Yu, X. & Jiang, G. 2016. Soil & tillage research effects of cattle manure compost combined with chemical fertilizer on topsoil organic matter, bulk density and earthworm activity in a wheat–maize rotation system in Eastern China. *Soil and Tillage Research* **156**, 140–147.

Hashemabadi, D., Zahiri Barsari, S., Zaredoost, F., Jadid Solymandarabi, M. & Feizi, H. 2020. Effects of planting date and nano fertilizers on quantity and quality features of saffron in Guilan. *Iranian Journal of Horticultural Science* **50**(4), 879–890.

Heydari, Z., Besharati, H. & Maleki Farahani, S. 2014. Effect of some chemical fertilizer and biofertilizer on quantitative and qualitative characteristics of Saffron. *Saffron agronomy and technology* **2**(3), 177–189.

Jabbari, M., Khayyat, M., Fallahi, H.R. & Samadzadeh, A. 2017. Influence of saffron corm soaking in salicylic acid and potassium nitrate on vegetative and reproductive growth and its chlorophyll fluorescence indices. *Saffron agronomy and technology* **5**(1), 21–35.

Jami, N., Rahimi, A., Naghizadeh, M. & Sedaghati, E. 2020. Investigating the use of different levels of Mycorrhiza and Vermicompost on quantitative and qualitative yield of saffron (*Crocus sativus* L.). *Scientia Horticulturae* **262**, 109027.

Jami-Alahmadi, M., Behdani, M.A. & Akbarpoor, A. 2009, May. Analysis of Agronomic Effective Factors on Yield of Saffron-Based Agro-Ecosystems in Southern Khorassan. In *III International Symposium on Saffron: Forthcoming Challenges in Cultivation, Research and Economics* **850**, 123–130.

Jiku, M., Sayem, A., Alimuzzaman, M., Singha, A., Rahaman, M., Ganapati, R.K., Alam, M. & Sinha, S.R. 2020. Response and productivity of garlic (*Allium sativum* L.) by different levels of potassium fertilizer in farm soils. *Bulletin of the National Research Centre* **44**(1), 1–9.

Khan, A.G. 2005. Role of soil microbes in the rhizospheres of plants growing on trace metal contaminated soils in phytoremediation. *Journal of trace Elements in Medicine and Biology* **18**(4), 355–364.

Khan, M.R. & Rizvi, T.F. 2017. Application of nanofertilizer and nanopesticides for improvements in crop production and protection. In *Nanoscience and plant–soil systems*. Springer, Cham, 405–427.

Khayyat, M., Jabbari, M., Fallahi, H.R. & Samadzadeh, A. 2018. Effects of corm dipping in salicylic acid or potassium nitrate on growth, flowering, and quality of saffron. *Journal of Horticultural Research* **26**(1), 13–21.

Khorramdel, S., Nasrabadi, S.E. & 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.

Khoshpeyk, S., Sadrabadi Haghghi, R. & Ahmadian, A. 2022. The effect of irrigation water quality and application of silicon, nanosilicon and superabsorbent polymer on the yield and active ingredient of saffron (*Crocus sativus* L.). *Journal of Saffron Research* **10**(1), 64–83.

Kianimanesh, K., Lebaschi, M.H., Jaimand, K., Abdossi, V. & Tabaei-Aghdaei, S.R. 2021. The Changes in Yield, Biochemical Properties and Essential Oil Compounds of Saffron (*Crocus sativus* L.) Plants Treated with Organic and Inorganic Fertilizers under Dryland Farming System. *Journal of Medicinal plants and By-product* **10**(1), 37–44.

Kirmani, N.A., Sofi, J.A., Bhat, M.A. & Ansar-Ul-Haq, S. 2014. Sustainable saffron production as influenced by integrated nitrogen management in Typic Hapludalfs of NW Himalayas. *Communications in soil science and plant analysis* **45**(5), 653–668.

Koocheki, A., Jahani Kondori, M. & Jahan, M. 2009, June. Effect of biofertilizer and inorganic fertilizer on generative growth and yield of saffron under high corn density. In *3rd International Symposium on Saffron Forthcoming Challenges in Cultivation Research and Economics*. Krokos, Kozani, Greece, 20-23 May 2009, p. 14.

Koocheki, A., Seyyedi, S.M. & Eyni, M.J. 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.

Koocheki, A. & Teimouri, S. 2014. Effect of age of farm, corm size and manure fertilizer treatments on morphological criteria of Saffron (*Crocus sativus* L.) under Mashhad conditions. *Applied Field Crops Research* **27**(105), 148–157.

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.

Koocheki, A., Fallahi, H.R., Amiri, M.B. & Ehyaei, H.R. 2015. Effects of humic acid application and mother corm weight on yield and growth of Saffron (*Crocus sativus* L.). *Agroecology* **7**(4), 442–425.

Koocheki, A., Jamshid Eyni, M. & Seyyedi, S.M. 2015a. The effects of mother corm size, manure and chemical fertilizers on replacement corm criteria and yield of saffron (*Crocus sativus* L.). *Journal of Saffron Research* **2**(1), 34–46.

Koocheki, A., Jamshid Eyni, M. & Seyyedi, S.M. 2015b. The effects of mother corm size and type of fertilizer on nitrogen use efficiency in saffron. *Saffron agronomy and technology* **2**(4), 243–254.

Lone, R., Shuab, R. & Koul, K.K. 2016. AMF association and their effect on metabolite mobilization, mineral nutrition and nitrogen assimilating enzymes in saffron (Crocus sativus) plant. *Journal of Plant Nutrition* **39**(13), 1852–1862.

Madahi, S., Parsa, M., Goldaniand, M. & Kafi, M. 2017. The effect of organic fertilizers and effective microorganisms (EM) on replacement corm criteria of saffron (*Crocus sativus* L.). *Saffron agronomy and technology* **5**(1), 37–49.

Mahmoodi, F., Mahdinezhad, N., Fakheri, B.A. & Ahmadian, A. 2021. Effect of silver nanoparticles and corm weight on physiological and morphological traits of saffron (*Crocus Sativus*) under Sistan climatic conditions. *Journal of Iranian Plant Ecophysiological Research,* **16**(61), 45–63.

Maleki Farahani, S. & Aghighi Shahverdi, M. 2015. Evaluation the effect of nono-iron fertilizer in compare to iron chelate fertilizer on qualitative and quantitative yield of saffron. *Journal of Crops Improvement* **17**(1), 155–168.

Malhotra, H., Pandey, R., Sharma, S. & Bindraban, P.S. 2020. Foliar fertilization: possible routes of iron transport from leaf surface to cell organelles. *Archives of Agronomy and Soil Science* **66**(3), 279–300.

Mandal, D. 2021. Nanofertilizer and its application in horticulture. *Journal of Applied Horticulture* **23**(1), 70–77.

Marques, A.P., Pires, C., Moreira, H., Rangel, A.O. & Castro, P.M. 2010. Assessment of the plant growth promotion abilities of six bacterial isolates using *Zea mays* as indicator plant. *Soil Biology and Biochemistry* **42**(8), 1229–1235.

Menia, M., Iqbal, S., Zahida, R., Tahir, S., Kanth, R.H., Saad, A.A. & Hussian, A. 2018. Production technology of saffron for enhancing productivity. J. Pharmacognos. *Phytochem* **7**(1), 1033–1039.

Mohammad, M., Amiri, M.E. & Sharghi, Y. 2012. Respond of saffron (*Crocus sativus* L.) to animal manure application. *Journal of Medicinal Plants Research* **6**(7), 1323–1326.

Mollafilabi, A. & Khorramdel, S. 2016. Effects of cow manure and foliar spraying on agronomic criteria and yield of saffron (*Crocus Sativus* L.) in a six year old farm. *Saffron agronomy and technology* **3**(4), 237–249.

Naghdibadi, H.A., Omidi, H., Golzad, A., Torabi, H. & FOTOUKIAN, M. 2011. Change in crocin, safranal and picrocrocin content and agronomical characters of saffron (*Crocus sativus* L.) under biological and chemical of phosphorous fertilizers. *Journal of medicinal plants* **10**(40), 58–68.

Naseer, S., Nehvi, F.A., Nagoo, S.A., Samad, S.S., Iqbal, A.M. & Dar, N.A. 2012, October. Effect of organic and inorganic sources of fertilizers on growth and yield of saffron (Crocus sativus L.). In *IV International Symposium on Saffron Biology and Technology 1200*, pp. 101–106.

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), 3342.

Nehvi, F.A., Lone, A.A., Khan, M.A. & Maqhdoomi, M.I. 2010. Comparative study on effect of nutrient management on growth and yield of saffron under temperate conditions of Kashmir. *Acta Horticulturae* **850**, 165–170.

Oftadeh, F.A., Aminifard, M.H., MORADINEZHAD, F. & Behdani, M.A. 2018. The effect of nitroxin on secondary metabolites in saffron (*Crocus sativus* L.). *Horticultural plant nutrition* **1**(1), 17–28.

Omidi, H.E.S.H.M.A.T., Badi, H.N., Golzad, A., Torabi, H. & Footoukian, M.H. 2009. The effect of chemical and bio-fertilizer source of nitrogen on qualitative and quantitative yield of saffron (*Crocus sativus* L.). *Journal of Medicinal Plants* **8**(30), 98–163.

Osmani Roudi, H.R., Masoumi, A., Hamidi, H. & Razavi, S.A. 2015. Effects of first irrigation date and organic fertilizer treatments on Saffron (*Crocus sativus* L.) yield under Khaf climatic conditions. *Saffron agronomy and technology* **3**(1), 33–25.

Parray, J.A., Kamili, A.N., Reshi, Z.A., Rehana, H. & Qadri, R.A. 2013. Screening of beneficial properties of rhizobacteria isolated from saffron (Crocus sativus L) rhizosphere. *African Journal of Microbiology Research* **7**(23), 2905–2910.

Parsa, H., Kheiry, A., Sani, K.M. & Razavi, F. 2018. The effect of nitrogen-fixing biofertilizers and urea on quantitative and qualitative traits of saffron (*Crocus sativus* L.). *Journal of saffron research* **6**(1), 141–153.

Pazoki, A., Kariminejad, M.K. & Foladi Targhi, A. 2017. Effect of corm density on yield and qualitative traits of saffron (*Crocus sativus* L.) under different urea and biological fertilizers in Shahr-E-Rey Region. *Journal of Crop Ecophysiology* **11**, 42(2), 315–330.

Rasool, A., Mir, M.I., Zulfajri, M., Hanafiah, M.M., Unnisa, S.A. & Mahboob, M. 2021. Plant growth promoting and antifungal asset of indigenous rhizobacteria secluded from saffron (*Crocus sativus* L.) rhizosphere. *Microbial Pathogenesis* **150**, 104734.

Rasouli, Z., Maleki Farahani, S. & Besharati, H. 2015. Saffron (*Crocus sativus* L.) yield as affected by different fertilizing systems. *Iranian Journal of Medicinal and Aromatic Plants Research* **31**(2), 204–219.

Rasouli, Z., Maleki Farahani, S. & Besharati, H. 2013. Some Vegetative Characteristics of Saffron (*Crocus sativus* L.) as Affected by Various Fertilizers. *Iranian Journal of Soil Research* **27**(1), 35–46.

Ren, X., Zhang, Q., Zhang, W., Mao, J. & Li, P. 2020. Control of aflatoxigenic molds by antagonistic microorganisms: Inhibitory behaviors, bioactive compounds, related mechanisms, and influencing factors. *Toxins* **12**(1), 24.

Rezaie, A., Feizi, H. & Moradi, R. 2019. Response of quantitative and qualitative characteristics of Saffron flower to the last irrigation cut-off time and various fertilizer resources. *Saffron agronomy and technology* **7**(1), 3–25.

Rezvani-Moghaddam, P. 2020. Ecophysiology of saffron. In *Saffron*, Woodhead Publishing, pp. 119–137.

Rivandi, H., Marvi, H. & Jami Moeini, M. 2016. The effect of soil and foliar application of effective microorganisms on growth characteristics of Saffron in the presence of chemical and organic fertilizers. *Saffron agronomy and technology* **4**(2), 105–117.

Rostami, M., Talarposhti, R.M., Mohammadi, H. & Demyan, M.S. 2019. Morpho-physiological response of Saffron (*Crocus Sativus* L.) to particle size and rates of zinc fertilizer. *Communications in Soil Science and Plant Analysis* **50**(10), 1250–1257.

Rostami, M., Maleki, M. & Effati, A.R. 2017. Effect of Foliar Application of Chemical Nano-Fertilizers on Physiological Traits of Saffron (*Crocus sativus* L). *Saffron agronomy and technology* **5**(4), 345–359.

Sabzevari, S., Khazaei, H. & Kafi, M. 2010. The effect of humic acid on germination of four cultivars of fall wheat (Saions and Sabaln) and spring wheat. *Journal of Agricultural Research* **8**(3), 473–480.

Salariyan, A., Mahmoodi, S., Behdani, M.A. & Kaveh, H. 2021. The effect of irrigation water quality, bio-fertilizer and nanoparticles of Fe on yield and some physiological traits of saffron (*Crocus sativus* L.). *Journal of Saffron Research*. https://dx.doi.org/10.22077/jsr.2021.4471.1164

Seyyedi, S.M., Ebrahimian, E. & Rezaei-Chiyaneh, E. 2018. Saffron daughter corms formation, nitrogen and phosphorous uptake in response to low planting density, sampling rounds, vermicompost and mineral fertilizers. *Communications in Soil Science and Plant Analysis* **49**(5), 585–603.

Shahriary, R., Rezvani Moghaddam, P., Jahan, M. & Khorasani, R. 2018. Effects of nutrition management on saffron (*Crocus sativus* L.) stigma and flower yield. *Saffron agronomy and technology* **6**(2), 181–196.

Shajari, M.A., Moghaddam, P.R., Ghorbani, R. & Koocheki, A. 2022. Does nutrient and irrigation managements alter the quality and yield of saffron (Crocus sativus L.)?. *Agricultural Water Management* **267**, 107629.

Shariatmadari, Z., Shoor, M., Rezvani Moghaddam, P., Tehranifar, A. & Ahmadian, A. 2018. Study the effects of organic and chemical fertilizers on replacement corms and flower characteristics of Saffron (*Crocus sativus* L.). *Saffron agronomy and technology* **6**(3), 291–308.

Shayganfar, A., Mohammadparast, B., Rostami, M. & Golfam, R. 2021. Salt stress causes a significant increase in anti-cancer crocins content of saffron stigma. *South African Journal of Botany* **143**, 61–68.

Shukla, P., Chaurasia, P., Younis, K., Qadri, O.S., Faridi, S.A. & Srivastava, G. 2019. Nanotechnology in sustainable agriculture: studies from seed priming to post-harvest management. *Nanotechnology for Environmental Engineering* **4**(1), 1–15.

Singh, R.P., Singh, P., Araujo, A.S., Ibrahim, M.H. & Sulaiman, O. 2011. Management of urban solid waste: Vermicomposting a sustainable option. *Resources, conservation and recycling* **55**(7), 719–729.

Singletary, K. 2020. Saffron: Potential health benefits. *Nutrition Today* **55**(6), 294–303.

Sofi, J.A., Kirmani, N.A., Sharma, V.K., Haq, S. & Chesti, M.H. 2013. Effect of integrated nutrient management in saffron. *Indian Journal of Horticulture* **70**(2), 274–278.

Solanki, P., Bhargava, A., Chhipa, H., Jain, N. & Panwar, J. 2015. Nano-fertilizers and their smart delivery system. In *Nanotechnologies in food and agriculture*. Springer, Cham, pp. 81–101.

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 & Environment* **7**(1), 19–23.

Usmani, Z., Kumar, V. & Mritunjay, S.K. 2017. Vermicomposting of coal fly ash using epigeic and epi-endogeic earthworm species: nutrient dynamics and metal remediation. *RSC advances* **7**(9), 4876–4890.

Vejan, P., Khadiran, T., Abdullah, R. & Ahmad, N. 2021. Controlled release fertilizer: A review on developments, applications and potential in agriculture. *Journal of Controlled Release* **339**, 321–334.

Wu, S.C., Cao, Z.H., Li, Z.G., Cheung, K.C. & Wong, M.H. 2005. Effects of biofertilizer containing N-fixer, P and K solubilizers and AM fungi on maize growth: a greenhouse trial. *Geoderma* **125**(1–2), 155–166.

Yarami, N. & Sepaskhah, A.R. 2015. Saffron response to irrigation water salinity, cow manure and planting method. *Agricultural Water Management* **150**, 57–66.

Zabihi, H. & Feizi, H. 2014. Saffron response to the rate of two kinds of potassium fertilizers. *Saffron agronomy and technology* **2**(3), 191–198.