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Effect of Vermicompost Application on Plant Growth Characteristics in Saffron (*Crocus sativus* L.) Cultivation

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The physical and chemical properties of soil play an important role in plant growth and health influencing mainly the quantity and quality of root and shoot growth via the availability of nutrients and water. Different Vermicompost-Soil mixture ratios (w/w) in addition to pure soil and pure vermicompost were used as growth media in this study. These media are as follows: V0 (0% Vermicompost + 100% Soil), V10 (10% Vermicompost + 90% Soil), V25 (25% Vermicompost + 75% Soil), V50 (50% Vermicompost + 50% Soil), V75 (75% Vermicompost + 25% Soil), and V100 (100% Vermicompost + 0% Soil). Results showed that all vermicomposting media caused an increase in plant height than pure soil medium. Active shoot, leaf, and flower number per plant showed an

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increasing tendency with the vermicomposting substrate but these results did not show statistical importance. Although stigma fresh and dry weight tended to increase with increasing vermicompost ratio in the soil statistically, the media shared the same statistical groups, pure vermicompost significantly decreased the parameters. The chemical properties of the growth media before-sowing and after-harvest were also analyzed, and it was observed that the amount of organic matter in the growing medium increased after harvest while the nitrogen concentration decreased. With the increase in vermicompost ratio in the soil, the fiber-forming and color matting of the tunics also increased statistically. Considering that the most important reasons for growing saffron are stigma and bulb yield, it is seen that vermicompost application does not have a statistical effect in terms of the fresh, and dry weight of stigma between pure soil and vermicompost-soil mixtures besides the negative effect of pure vermicompost. In addition, although V25, and V50 applications seem to be superior to lesser and higher vermicomposting medium in total corm yield, the fact that V0 (%100 Soil) gives the best result in terms of dry matter has revealed the unnecessariness of vermicompost application.

Keywords: Daughter corm yield; organic fertilizer; overdose; saffron growth; stigma yield; tunics; vermicompost.

1. INTRODUCTION

Saffron (*Crocus sativus* L.) is widely grown in different parts of the world, especially in the Mediterranean basin. It requires intense manual labor from planting to collecting stigmas. The stigmas of the flowers are collected to obtain the spice, which is the most valuable part (Cicco, 2022). This plant belongs to the genus *Crocus* of the family *Iridaceae* (Kamra et al., 2023), which includes about 80 species native to the Mediterranean basin and southwestern Asia (Fernández, 2004). Considered the most expensive spice in the world due to the color, bitterness, and aromatic power of its dried stigmas, saffron certainly represents the most interesting and attractive species (Gresta et al., 2008; Cardone et al., 2020). Saffron, which is a perennial plant, requires sandy to sandy loam soils, therefore, the addition of N fertilizer considerably affects the amount and quality of yield (Kumar et al., 2008). Farmyard manure is frequently applied to saffron fields to improve both the content of organic matter and nutrients of soils in addition to plant quality and quantity factors (Gresta et al., 2008 Esmaeilian et al., 2022). Some studies show that the use of vermicompost with some other substances is also beneficial (Jami et al., 2020; Feizi et al., 2021).

In general, earthworms decompose a variety of organic wastes; mineralization rates increase, and quickly transform into humus-like materials with a finer texture than compost. This new structure, called vermicompost, has more diverse microbial activity (Atiyeh et al., 2000; Enebe & Erasmus, 2023). It has been reported that the significant effects of humic acid included in worm compost on plant growth are most likely due to its hormone-like activity or may be due to plant growth hormones absorbed on humates (Atiyeh et al., 2002; Olle, 2023). Nutrient and mineral concentrations in vermicompost are higher than in commercial fertilizers, depending on the earthworm's activities and production processes (Katheem-Kiyasudeen et al., 2015). These researchers reported that the total C and N concentrations in vermicomposts are higher than in other composts, and total N contents range from 1% to 2.1%. There are also the appropriate amounts of macro- and micro-nutrients in vermicomposts (Pathma & Sakthivel, 2012), and they have more minerals like N, P, K, Ca, and Mg that commercial rooting media (Arancon et al., 2004; Joshi et al., 2015).

Investigating the possibilities of growing special plants such as saffron in small areas will make very important contributions to rural life and increase the quality of life of farmers. Growing special crops in small areas requires special care, especially fertilization. Adding clean (weed seed-free) and high-nutritional-value organic materials like vermicompost to soil can increase both crop yield and quality while reducing maintenance costs. But sometimes the excessive usage of these inputs may damage the plant and cause unnecessary costs. To reach the correct conclusion, it is necessary to conduct plant-specific scientific studies.

This study aimed to investigate the effects of Vermicompost-Soil mixtures in different ratios besides pure soil and pure vermicompost substrates on plant growth that is effective on

saffron quality and quantity in the plant cultivation step. In addition, the saffron-grown vermicomposted substrates were analyzed before sowing and after harvest, and changes in their chemical properties were investigated.

2. MATERIAL AND METHODS

2.1 Growing Conditions, and Experimental Design

The study was carried out in a greenhouse condition from September 2018 to June 2019 at the agricultural research areas of Kocaeli University. Saffron corms (Fig. 1a) were purchased from a professional saffron grower from Safranbolu where the most famous saffron growing town in Karabük province in Türkiye is.

The newly harvested and purchased corms in May 2018 were used. The healthy ones were selected and stored in a dark and airy environment until sowing time, September 2018. Just before the sowing, the corms were first classified according to their size and those with diameters of 27, 28, 29, and 30 mm were used in the study. Each application consisted of the same diameter corms to avoid the corm size effect (2 of 27 mm, 2 of 28 mm, 3 of 29 mm, 3 of 30 mm in diameter corms in each repeat). Secondly, the corms were transferred to black polyethylene bag-type pots of 2 dm^3 capacity (1 plant per pot,10 plants per replicate, and 30 plants per treatment) (Fig. 1B) on September 4th, 2018, and placed in the research greenhouse. The properties of the soil, used in the experiment were determined according to methods detailed in Page et al*.,* (1987) and given in Table 1.

Vermicompost (100% organic) which is trademarked and purchased from a professional vermicompost producer, was used for the experiment with or without soil in the following ratios according to the weight principle (w/w):

V0: 0% Vermicompost + 100% Soil
V10: 10% Vermicompost + 90% Soil
V25: 25% Vermicompost + 75% Soil
V50: 50% Vermicompost + 50% Soil
V75: 75% Vermicompost + 25% Soil
V100: 100% Vermicompost + 0% Soil

Some initial chemical properties of the pure vermicompost and the soil are given in Table 1. Before sowing and after harvesting, these parameters were compared in the same vermicompost-soil mix and pure vermicompost, and the references for analysis methods are given in Table 6.

Irrigation was carried out at regular intervals every two weeks by calculating the plant water consumption. After the 7th month, irrigation was stopped with the slowing of the growth of the above-ground parts of the plants and the yellowing of the leaf tips.

2.2 Quantitative and Qualitative Parameters of Plant Growth and Obtaining Data

Quantitative and qualitative parameters were measured in all plants from all sowed bulbs in pots along with study months.

Active shoots: All shoots that came from the main corm or from the daughter corms formed over time, that are active and capable of giving leaves and/or flowers were counted, and averages were given as per plant (Fig. 2A).

Plant height: The part of the leaves formed in the shoots of the corms planted in pots from the substrate surface to the longest leaf tip was measured with a ruler and the averages were given as cm per plant (Fig. 3A).

Leaf number: All leaves consisting of both mother corm and daughter corms were counted and the total number was determined, and the average number of leaves was given as per plant.

Table 1. Physical and chemical properties of soil and vermicompost used in the experiment

Soil (100 %)									
Fractions (%)		**Texture**	**pH**	**EC (dS m^{-1})**	**Organic Matter (%)**	**Some available macronutrients (mg kg^{-1})**			
Clay	**Sand**					**P_2O_5**	**K_2O**	**Ca**	**Mg**
32.3	36.9	CL	6.48	0.86	1.93	30.0	152.0	5153	1004
Vermicompost (100%)									
pH	**EC (dS cm^{-1})**	**Organic Matter (%)**	**Some total macro- and micro-nutrients (%)**						
			N	**P**	**K**	**Ca**	**Mg**	**Fe**	
6.71	7.68	62.88	2.76	1.26	1.30	1.68	0.74	0.39	



(A) **(B)**

Fig. 1. *Crocus sativus* L.; A) After purchased from a saffron grower before being arranged according to their diameter, B) The plants that continue to develop in 1st, 2nd, and 3rd repeat in 5th month at 75% Vermicompost (V75)



(A) **(B)** **(C)**

Fig. 2. *Crocus sativus* L.; A) Active shoots in 10% Vermicompost (V10) substrate after 6th month, B) A flowering sample, C) Harvested stigma samples from different vermicompost applications

Flower number: All the flowers were collected early in the morning. It was obtained by dividing the total number of flowers obtained at the end of flowering by the number of plants in the relevant replication and flower numbers were given as per plant (Fig. 2B).

Stigma length: The stigmas (only from the beginning red part of it) separated from the collected flowers were measured when they were fresh and divided by the number of flowers obtained from the relevant application and average stigma length was found and given as cm per stigma (Fig. 2C).

Stigma fresh and dry weight: The fresh stigmas were picked up daily and were weighed before and after drying under normal laboratory conditions in the dark until they reached a constant weight (within one week), and results were given as mg per stigma.

Stigma dry matter: After the weighting of fresh and dried stigmas, dry stigma matter was calculated as a percentage.

Corm number, weight, diameter, and yield: At the end of the growth period, after the daughter corm removing from the substrate in June, 4th, 2019, the total replacement corm number (per plant), large size (>3 cm) replacement corm number (per plant), total replacement corm yield (g/plant), large size (>3 cm) replacement corm weight (g/corm), and average diameter of all replacement corms (mm/corm) at least more than 1 cm in diameter were measured and calculated (Fig. 3B, Fig. 3C).

Appearance of tunics: It showed visual changes in tunica structures (corm skin) when daughter corms were removed. The covering tunics of daughter corms have been graded as “smooth-bright-light color” and “fibrous-matte-

dark color". The percentages of the appearance of tunics were calculated by visual counting the corms in each application and smoot-bright-light color ratios were given as percentages (Fig. 4A).

Corm dry matter: After the corm removal and fresh corm measurement, three corms of similar size (30 mm in diameter) from each application were weighed before and after drying in an oven at 105 °C until they reached a constant weight, the dry matter was calculated as a percentage of them (Fig. 4B, Fig. 4C).

2.3 Chemical Changes in Vermicompost-Soil Mixtures

At the beginning and end of the experiment, all vermicompost-soil mixtures (V10, V25, V50, V75 and V100) were analyzed according to the methods given in Table 6. The averages of the analyzed parameters [pH, EC (µS/cm), Organic Matter-OM (%), Total N (%), Total P (%), Total K (%), Total Ca (%), Total Mg (%), Total Fe (%), Total Mn (mg kg^{-1}), Total Cu (mg kg^{-1}), and Total Zn (mg kg^{-1})] were compared.

2.4 Statistical Analysis

The experiment was designed as a Randomized Complete Block Design with three replicates each consisting of 10 plants (each application consisted of 30 plants) and a total of 6 applications were treated (V0, V10, V25, V50, V75, and V100). Totally 180 plants were evaluated for each parameter. To test the significance level of the treatments, Duncan's Multiple Range Test analysis at least $P<0.05$ level was performed along with one-way ANOVA implemented SPSS-16 software.



(A) **(B)** **(C)**

Fig. 3. *Crocus sativus* L.; A) A plant height measurement sample, B) The replacement corm removed at the end of the 9th month at 25% Vermicompost (V25) substrate, C) The replacement corm sample from only one plant at 75% Vermicompost substrate (V75)



(A) **(B)** **(C)**

Fig. 4. *Crocus sativus* L.; A) The corm tunic samples from 100% Soil (V0) (smooth-bright-light colored at left three replacement corms) and from 100% Vermicompost (V100) (fibrous- matte-dark colored at right three corms), B) The fresh corm sample before dried obtained from 50% Vermicompost (V50) substrate, C) The dried corm sample after drying process obtained from 50% Vermicompost (V50) substrate

Table 2. Effects of vermicompost-soil substrates on the features of above-ground organs of saffron plant

Vermicompost Quantity in Soil (w/w) (%)	Active Shoots (per plant)	Plant Height (cm/plant)	Leaf Number (per plant)	Flower Number (per plant)
V0	$4.51^{\pm1.01}$	$38.92^{\pm2.63}$ c	$17.03^{\pm1.70}$	$0.32^{\pm0.20}$
V10	$6.24^{\pm1.51}$	$43.82^{\pm2.66}$ b	$23.37^{\pm3.81}$	$0.56^{\pm0.25}$
V25	$5.06^{\pm0.86}$	$51.93^{\pm3.15}$ a	$20.29^{\pm1.68}$	$0.39^{\pm0.10}$
V50	$4.81^{\pm0.23}$	$47.71^{\pm2.56}$ ab	$21.19^{\pm3.50}$	$0.53^{\pm0.19}$
V75	$4.95^{\pm0.38}$	$51.19^{\pm1.58}$ a	$19.77^{\pm1.54}$	$0.27^{\pm0.21}$
V100	$5.27^{\pm1.03}$	$47.41^{\pm2.06}$ ab	$23.54^{\pm6.35}$	$0.60^{\pm0.35}$
F - value	ns	P<0,01	ns	ns

**Values are the mean of three replicates (means ± SE, n= 3). Different letters in the same column are significantly different according to Duncan's Multiple Range Test.*

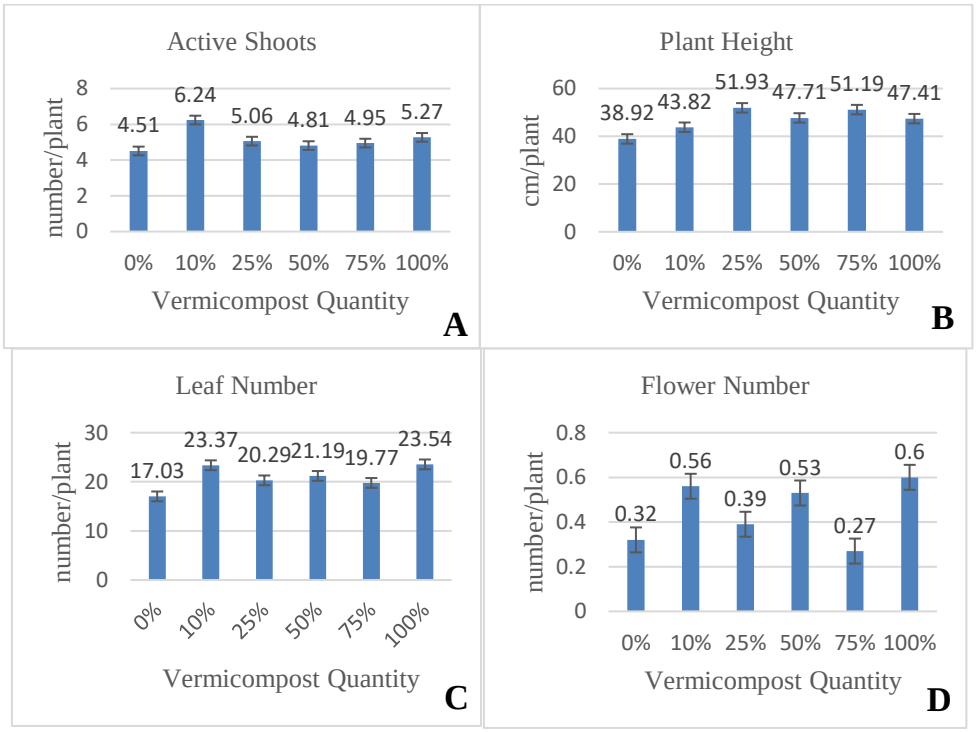

Fig. 5. Effects of vermicompost usage on above-ground features of *Crocus sativus* L.; A) Active shoots, B) Plant height, C) Leaf number, d) Flower number in vermicompost quantity (w/w) at the mixture of V0, V10, V25, V50, V75, and V100

3. RESULTS

3.1 Quantitative and Qualitative Parameters of Plant Growth

Active shoots obtained from the main saffron corm, number of leaves, and number of flowers tended to increase with some of the increasing vermicompost ratios in the soil. However, a notable interaction could not be found between the substrates and the number of active shoots, number of leaves, and number of flowers. However, mixtures (V10, V25, V50, and V75), and pure vermicompost (V100) significantly affected plant height. The mixture of V10, V25, V50, and V75, and vermicompost (V100) caused an increase in plant height by 12.6%, 33.4%, 22.6%, 31.5%, and 21.8%, respectively (Table 2, Fig. 5).

The effects of Vermicompost-Soil mixtures on the total replacement corm numbers, and the average diameter of replacement corms were not found considerably, and these daughter corm parameters tended to increase with the effect of applications, compared to the control pure soil (V0). However, notable interactions between applications and the large-size (>3 cm) daughter corm number-weight, total replacement corm yield, and percentage of dry matter were found.

While the large-size daughter corm (>3 cm) weight tended to increase with V25, V50, and V75 applications, it tended to decrease with the vermicompost (V100) application. The V10, V25, V50, and V75 caused a significant increase in the total yield of daughter corms by 55.5%, 91.3%, 89.5%, and 67.1% respectively. In contrast, all mixtures (V10, V25, V50, and V75) and vermicompost (V100) caused a significant decrease in the dry matter of daughter corms by 12.5%, 16.8%, 21.5%, 22.8%, and 28.8%, respectively (Table 4, Fig. 7).

The appearance of tunics from smooth-bright-light color to fibrous-matte-dark color was significantly decreased from pure soil to pure vermicompost statistically. The decreases in comparison to pure soil (V0) were by 25,1%, 62.6%, 71.0%, 92.8%, and 95.8% respectively from V10 to V100 (Table 5, Fig. 8).

The interactions between the substrates and the fresh weights, dry weights, length, and dry matter ratio of the stigma were found to be significant. In comparison with the control (100% Soil=V0), pure vermicompost application significantly decreased the fresh and dry weights of the stigma by 37.3% and 47.4%, respectively. Stigma dry matter showed an increasing tendency except for V100 statistically (Table 3, Fig. 6).

Table 3. Effects of vermicompost-soil substrates on features of the stigma of saffron plant

Vermicompost Quantity in Soil (w/w) (%)	Stigma Length (cm/stigma)	Stigma Fresh Weight (mg/ stigma)	Stigma Dry Weight (mg/ stigma)	Stigma Dry Matter (%)
V0	$3.24^{\pm0.55}$ b	$30.3^{\pm4.0}$ a	$5.7^{\pm1.4}$ a	$18.69^{\pm2.29}$ ab
V10	$3.77^{\pm0.17}$ ab	$31.3^{\pm4.2}$ a	$5.7^{\pm0.6}$ a	$18.17^{\pm1.69}$ ab
V25	$3.89^{\pm0.18}$ ab	$36.0^{\pm1.0}$ a	$6.3^{\pm0.6}$ a	$17.57^{\pm1.18}$ ab
V50	$3.84^{\pm0.10}$ ab	$34.0^{\pm5.2}$ a	$6.7^{\pm1.5}$ a	$19.46^{\pm1.94}$ ab
V75	$3.98^{\pm0.60}$ a	$33.0^{\pm2.7}$ a	$7.3^{\pm0.6}$ a	$22.37^{\pm3.21}$ a
V100	$3.30^{\pm0.25}$ ab	$19.0^{\pm1.0}$ b	$3.0^{\pm1.0}$ b	$15.63^{\pm4.45}$ b
F - value	*P*<.05	*P*<.01	*P*<.01	*P*<.05

**Values are the mean of three replicates (means ± SE, n= 3). Different letters in the same column are significantly different according to Duncan's Multiple Range Test.*

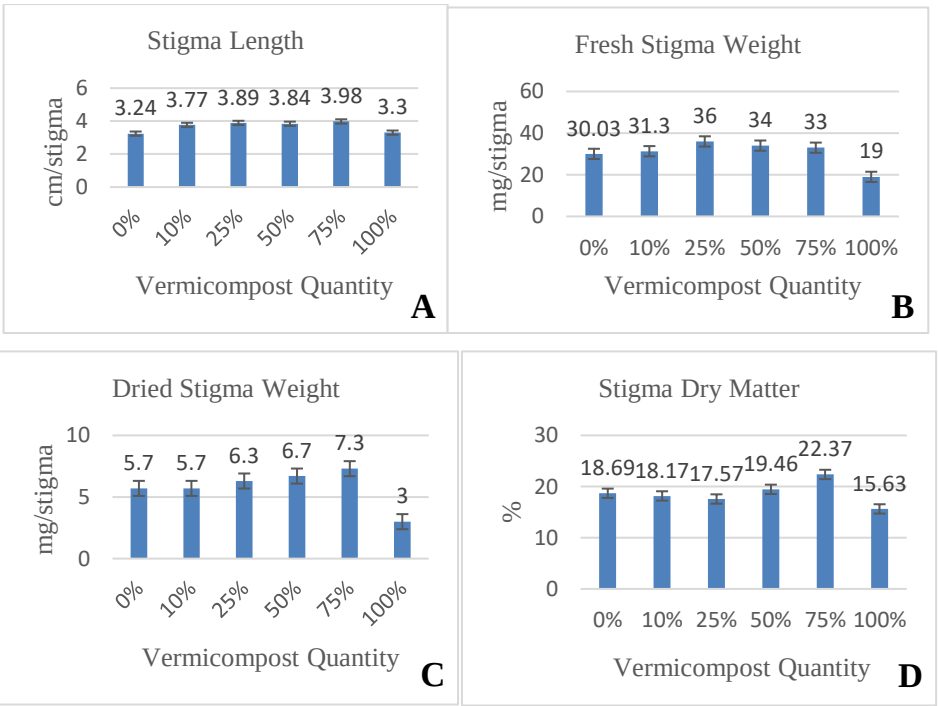

Fig. 6. Effects of vermicompost usage on qualitative and quantitative features of stigmas of *Crocus sativus* L.; A) Stigma length, B) Fresh stigma weight, C) Dried stigma weight, D) Stigma dry matter in vermicompost quantity (w/w) at the mixture of V0, V10, V25, V50, V75, and V100

Table 4. Effects of vermicompost-soil substrates on the features of replacement corm of saffron plant

Vermicompost Quantity in Soil (w/w) (%)	Total replacement corm numbers (per plant)	Large Size (>3 cm) replacement corm Number (per plant)	Total replacement corm yield (g plant^{-1})	Large Size (>3 cm) replacement corm weight (g corm^{-1})	Average diameter of replacement corm (mm)	Dry matter of replacement corm (%)
V0	$4.33^{\pm0.78}$	$0.54^{\pm0.22}$ b	$14.89^{\pm1.86}$ d	$13.71^{\pm1.06}$ abc	$19.12^{\pm3.66}$	$38.21^{\pm1.08}$ a
V10	$6.14^{\pm1.69}$	$0.72^{\pm0.20}$ ab	$23.15^{\pm3.73}$ bc	$12.78^{\pm1.36}$ bc	$19.27^{\pm2.48}$	$33.45^{\pm1.22}$ b
V25	$5.20^{\pm1.07}$	$0.92^{\pm0.32}$ ab	$28.48^{\pm2.58}$ a	$16.52^{\pm1.92}$ a	$21.68^{\pm1.42}$	$31.78^{\pm2.65}$ bc
V50	$5.04^{\pm0.64}$	$1.03^{\pm0.14}$ a	$28.22^{\pm3.25}$ a	$15.01^{\pm0.57}$ ab	$22.70^{\pm1.30}$	$29.99^{\pm0.59}$ c
V75	$4.95^{\pm0.42}$	$0.85^{\pm0.13}$ ab	$24.88^{\pm2.03}$ ab	$14.47^{\pm2.41}$ abc	$22.45^{\pm0.50}$	$29.48^{\pm1.35}$ cd
V100	$4.67^{\pm1.33}$	$0.84^{\pm0.06}$ ab	$19.26^{\pm2.12}$ cd	$11.87^{\pm0.93}$ c	$22.03^{\pm1.95}$	$27.21^{\pm0.75}$ d
F - value	ns	*P*<.05	*P*<.01	*P*<.05	ns	*P*<.01

**Values are the mean of three replicates (means ± SE, n= 3). Different letters in the same column are significantly different according to Duncan's Multiple Range Test*

Table 5. Effects of vermicompost-soil substrates on the appearance of replacement corm tunics of saffron plant

Vermicompost Quantity in Soil (w/w) (%)	Appearance of Tunics (smooth-bright-light color) (%)
V0	$88.99^{\pm3.70}$ a
V10	$66.73^{\pm6.62}$ b
V25	$33.28^{\pm11.43}$ c
V50	$25.76^{\pm7.72}$ c
V75	$6.43^{\pm1.46}$ d
V100	$3.71^{\pm3.26}$ d
F - value	*P*<.01

**Values are the mean of three replicates (means ± SE, n= 3). Different letters in the same column are significantly different according to Duncan's Multiple Range Test.*

3.2 Chemical Changes in Vermicompost-Soil Mixtures

At the end of the experiment, the changes in the nutrient content of the vermicompost-soil mixtures (V10, V25, V50, V75, and V100) after harvest are given in Table 6. The pH values increased by 12.7% in the V10 mixture compared to the beginning. Increases in the pH value of the other mixing ratios varied between 4.2% and 5.2%. The EC values of mixtures decreased. These decreases in the mixtures (V10, V25, V50, and V75) and 100% vermicompost were 56.5%, 64.6%, 50.6%, 58.5%, and 56.8%, respectively (Table 6).

At the end of the experiment, the organic matter contents in all mixtures increased except for the V25. The highest increase was found in the V50 mix, with an increase of 12.4%. Following this came the V10, V100, and V75, with increases of 7.4%, 4.8%, and 4.5%, respectively. Contrarily, the total nitrogen contents of all mixtures showed a reduction of 21.7% (V25), 14.3% (V75), 9.8% (V10), and 14.1% (V100). V50 mix increased the increased the total nitrogen content by 9.4% (Table 6).

The changes in the total macro- and micronutrient concentrations of all mixtures at the end of the experiment are given in Table 6. Total P concentrations increased by 10% and 60% in the V10 and V50 mixtures, respectively, while it decreased by 45.5%, 25.5%, and 3.2% in the V25, V75, and V100 mixtures, respectively. Total K concentrations decreased in all mixtures. These decreases in the V10, V25, V50, V75, and V100 were 15.8%, 5.3%, 13.5%, 22.6%, and 40.8%, respectively.

Total Ca concentrations decreased in V10, V25, V75, and V100 by 5.4%, 15.9%, 10.9%, and 11.3%, respectively, but increased in the V50 mix by 4.7%. Similarly, total Mg concentrations showed decreases in V10, V25, V50, and V100 at different rates, but the V75 mix showed an increase of 3.9% (Table 6).

Total Fe concentration increased in V75 and V100 by 6.9% and 7.9%, respectively, whereas it decreased in V10 and V50 mixtures by 2.2% and 11.3%, respectively. Total Cu concentrations showed increases in V50 and V75 by 21.9% and 7.1%, respectively, but this parameter showed decreases in V25 and V100 by 31.0% and 3.2%,

respectively (Table 6). Total Mn and Zn concentrations decreased in all mixtures (V10, V25, V50, V75, and V100). These decreases in mixtures were found for Mn concentrations at 14.7%, 9.6%, 6.2%, 49.4%, and 44.0%, respectively. Similar decreases were found for Zn concentrations at 5.0%, 32.8%, 32.6%, 3.6%, and 2.2%, respectively (Table 6).

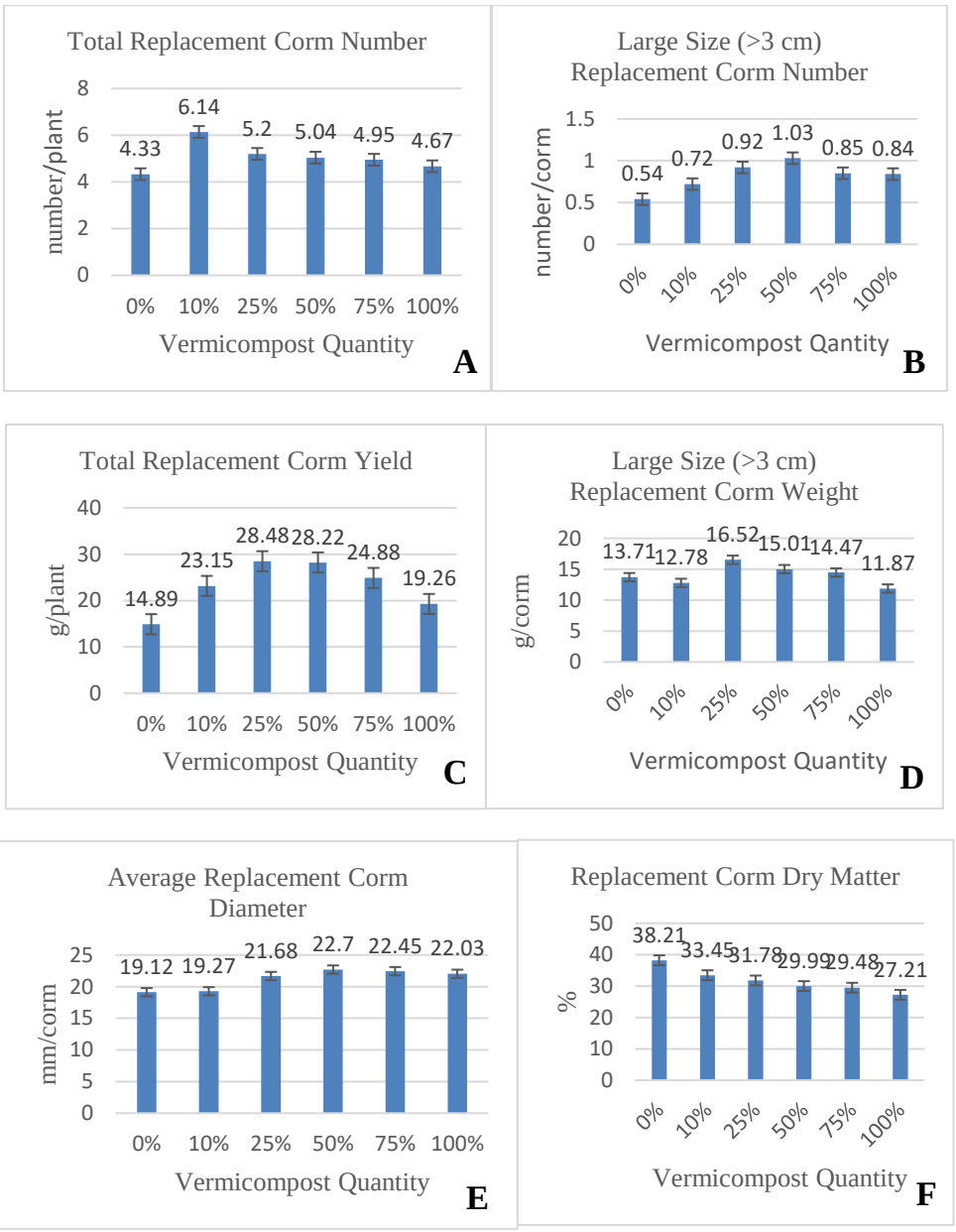

Fig. 7. Effects of vermicompost usage on qualitative and quantitative features of replacement corms of *Crocus sativus* L.; a) Total replacement corm number, b) Large size (>3 cm) replacement corm number, c) Total replacement corm yield, d) Large size (>3 cm) replacement corm weight, e) Average replacement corm diameter, f) Replacement corm dry matter in vermicompost quantity (w/w) at the mixture of V0, V10, V25, V50, V75, and V100

Table 6. The chemical change in the nutrients in the used vermicomposted substrates at the beginning and the end of the experiment

Properties	At the beginning of the experiment					At the end of the experiment					Method of analysis
	V10	V25	V50	V75	V100	V10	V25	V50	V75	V100	
pH	5.50	6.37	6.50	6.67	6.71	6.20	6.67	6.84	6,95	6,99	Skoog et al., (1998)
EC (µS/cm)	409	883	1610	3400	7680	178	313	795	1410	3320	
OM (%)	9.73	13.33	17.96	31.00	62.88	10.45	11.68	20.18	32.40	65.91	Anonymous (2019)
Total N (%)	0.51	0.69	0.85	1.47	2.76	0.46	0.54	0.93	1.26	2,37	Anonymous (1996)
Total P (%)	0.10	0.22	0.23	0.55	1.26	0.11	0.12	0.37	0,41	1,22	Kacar and Kütük (2010)
Total K (%)	0.19	0.19	0.37	0.62	1.30	0.16	0.18	0.32	0.48	0.77	
Total Ca (%)	0.74	0.81	0.86	1.28	1.68	0.70	0.69	0.90	1.14	1.49	
Total Mg (%)	0.86	0.83	0.86	0.76	0.74	0.83	0.79	0.83	0.79	0.68	
Total Fe (%)	5.37	4.60	4.70	2.90	0.39	5.25	4.62	4.17	3.10	0.42	Anonymous (2022)
Total Mn (mg kg^{-1})	1282	1202	1129	844,6	793,0	1094	1087	1059	427,6	444,2	
Total Cu (mg kg^{-1})	41.66	60.88	68.10	120,1	233,8	41.64	42.02	83.0	128,6	226,4	
Total Zn (mg kg^{-1})	58.84	93.48	163,2	225,6	453,8	55.88	62.78	110.0	217,4	444,0	

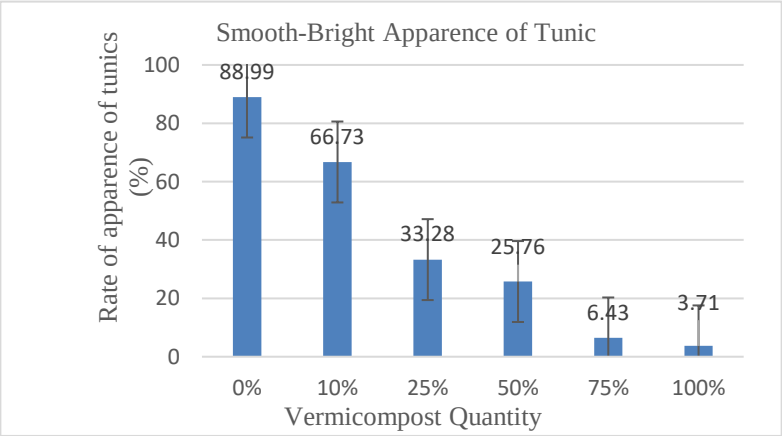

Fig. 8. Effects of vermicompost usage on the rate of smooth-bright-light color in the appearance of tunics in vermicompost quantity (w/w) at the mixture of V0, V10, V25, V50, V75, and V100

4. DISCUSSION

One of the most important issues during saffron production is the good nutrition of the plant. When the nutrition-growth-yield relationship of the plant is examined well, the changes in the below-ground or above-ground organs are the best indicator of the contribution made to the plant rooting environment. Although saffron does not require very fertile soil, chemical and organic fertilization plays an important role in its cultivation (Kumar et al., 2008).

In our study, it was determined that Vermicompost-Soil mixtures had significant effects on some of the growth parameters of the saffron plant. All mixtures and pure vermicompost increased the plant height, compared to the pure soil (V0). They also positively affected the number of active shoots,

leaves, and flowers per plant (Table 2). These positive effects may be related to the increase in hormones such as auxin and gibberellin after vermicomposting or the humic substances formed because of increased microbial activity during vermicomposting (De Sanfilippo et al., 1990). With the application of organic fertilizers, plant growth optimization was achieved, and it was observed that there was an improvement in the weight of the daughter corms and an increase in saffron flower and stigma weights (Kocheki et al., 2011). It has been reported an increase in stigma dry yield, leaf number and length, leaf fresh weight, and chlorophyll contents with the use of 1000 kg da^{-1} vermicompost (Fadafen et al., 2017). Also, Aytekin & Açıkgöz (2008) stated that vermicompost (bio-humus) application together with effective microorganisms was effective on saffron yield parameters such as the number of flowers, plant height, and the number of leaves.

Stigmas, the most valuable part of saffron flowers, are not a storage organ and therefore the increase in nutrients in the rooting medium may not be directly related to the increase in stigma length. The yield and quality of saffron could be achieved by more flowers per plant with a higher number of stigmas (Fernández, 2004). In this study, fresh and dry weights of stigma tended to increase by the applications, except for pure vermicompost (V100) (Table 3). These results are in agreement with the results reported by Koocheki et al., (2011), who stated that bio-fertilizer usage of up to 25 % contributes to the increase in flower number and stigma yield. However, pure vermicompost (V100) significantly decreased the fresh and dry weights of stigma (Table 3). This could be corcerning the negative effects of an overdose of vermicompost. When used in appropriate dosage and properties, organic materials decompose, and plant nutrients and organic compounds released into the soil improve crop growth and yield characteristics. But when large amounts of organic matter are added to the soil, microorganisms need more nitrogen to decompose carbon in immature compost. Plants grown in this environment could suffer from severe nitrogen shortages and their growth may get slower. Emino & Warman (2004) reported that the phytotoxic effects of organic material on plants could be due to its effect on seed germination, root growth or both.

Unlike other plants, the root growth of the saffron plant continues from the autumn to the spring period. During this time, the mother bulb is empty and produces daughter bulbs to continue the plant lineage (Gresta et al., 2008). The mother corm produces 1-3 medium/large daughter corms from the apical buds, according to its size, and produces a few small corms from the lateral buds. Our results show that the numbers and weights of large-size daughter corm tended to increase, compared to the soil, except for the application of pure vermicompost (Table 4). These increases could be related to the nutrient contents of the vermicompost, especially N and P (Table 1). Seyyedi et al. (2018) stated that especially organic fertilizers have an effective role in the formation of daughter corms. In addition, daughter corm number showed an increase with especially V10 and V25 applications. The average diameter of the daughter corm showed an increase especially above V25 applications. Both of them could be related to organic fertilizer applications provide growth optimization and increase the development of the daughter corms and thus saffron flower and stigma yield (Koocheki et al., 2011). On the other hand, these increases could also be associated with the increase in the macro and micronutrients and thus the total number of daughter corms (De Sanfilippo et al., 1990). However, the dry matter of the daughter corm significantly decreased with all mixtures (Table 4).

As seen in Table 5, decreases were observed in the percentage of smooth-bright-light color appearance of tunics depending on the increase in organic matter (Fig. 4a). Color matting and forming fiber due to the increase in organic matter in tunics is a parameter observed for the first time in literature. Covering the corms with a reticulated fibrous tunic could be to protect them from the negative effects of excess organic matter. It was stated that higher concentrations of humic materials could cause a decrease in plant growth (Chen & Aviad, 1990).

Analysis of the mixed and pure vermicompost after harvest showed that the amounts of organic matter in these applications increased while the total amounts of N decreased (Table 6). This indicates that the vermicompost was not fully matured before application. The presence of immature vermicompost with a high C/N ratio in the growing medium may also negatively affect seed germination and plant growth (Singh & Singh, 2017).

In the chemical analyses performed after harvest, decreases were found in examined

macronutrients (P, K, Ca, and Mg) and micronutrients (Mn and Zn) concentrations, except for Fe and Cu (Table 6) in some substrates. It is reported that the 8-ton da^{-1} of tomato fruit lifted up 21 kg da^{-1} of N, 5 kg da^{-1} of P, and 33.6 kg da^{-1} of K from the soil. Similarly, 2-ton da^{-1} of potato tubers took up 17 kg $da^{-1}$of N, 4.6 kg $da^{-1}$of P, and 22.5 kg da^{-1} of K (Kacar, 2013).

5. CONCLUSION

The results obtained with this study showed that different ratios of vermicompost-soil mixtures positively affected some of the growth parameters of saffron. While active shoot numbers, number of leaves, number of flowers, replacement corm number, and diameter of replacement corms were affected only numerically, plant height was affected statistically by the mixtures. However, pure vermicompost caused a decrease in the stigmas (the most valuable part of the saffron plant) fresh weights, dry weights, and dry matter. This negative effect may be related to the maturation of the vermicompost. The increase in the amount of organic matter in the analysis performed after the harvest also supports this hypothesis. More research should be performed to fill the gaps in the instability of the nutritional values of the immature organic fertilizer and the lack of expected yield increases.

In addition, depending on the amount of organic matter, the increase in fiber formation and matting and getting darkening of color in the tunics of corms should also be investigated. As a result of using these corms as the main corm in production, investigating the changes in important parameters such as the formation of daughter corm and stigma yield may contribute to saffron production.

We concluded that either non-matured vermicomposting substrates negatively affected some of the important growth or quality features as in corm dry matter, or showed ineffectiveness as in stigma fresh and dry matter. In addition, ineffectiveness was observed in the number of active shoots, leaves, flowers, and replacement corms, besides the diameter of the replacement corm of the saffron plant. These results are remarkable considering that vermicompost fertilizer comes at a cost.

On the other hand, saffron is an alternative crop for sustainable agriculture in marginal agricultural fields due to its unique biological, physiological, and agronomic properties. It is an important source of income for small family businesses in rural with its input cost, economic value, and production experience. To get the best results in agriculture, the amount of organic fertilizer, including vermicompost, should be expanded with training and practices. Also, detailed studies should be carried out on the nutritional and yield relationships of this plant with long-term field trials.

DISCLAIMER (ARTIFICIAL INTELLIGENT)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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