Akademik Ziraat Dergisi 13(1): 137-148 (2024)
ISSN: 2147-6403 e-ISSN: 2618-5881 DOI: http://dx.doi.org/10.29278/azd.1410685

Araştırma (Research)

Research on the Use of Organic Fertilizer Instead of Chemical Fertilizer and Its Effect on the Morphological and Yield in Fennel Plant*

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*This study was funded by the Scientific Research Projects Coordination Unit (Project code: 2021.10.07.1493) (BAIBU-BAP), Faculty of Agriculture, Bolu Abant İzzet Baysal University, Türkiye.

Alınış tarihi: 27 Aralık 2023, Kabul tarihi: 23 Mayıs 2024

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Abstract

Objective: Organic manures can be used as an alternative method to replace chemical fertilizers for sustainable agricultural production. Sheep manure and vermicompost are the most important alternative applications. These manures can increase soil fertility, plant productivity, and quality. Fennel (*Foeniculum vulgare* L.) has been used as a medicinal and aromatic plant throughout human history, and it is widely used as a food additive, pharmacological substance, and medicinal application.

Materials and Methods: This study was conducted to determine the effect of different organic applications (sheep manure (SM) and vermicompost manure (VM)-10, 15, and 20 t/ha) and chemical fertilizer (Ammonium sulfate (AS)-40, 80, and 120 kg/ha) with a control (no fertilizer or manure) on the morphology, yield, and essential oil, and fixed oil yield of fennel. Results: The results of the study showed that significant statistical differences were found only in plant height and the fixed oil yield of fennel. The fruit yield ranged from 90.14 kg/da to 122.72 kg/da, and the 80 kg/ha ammonium sulfate (AS-2) and 10 t/ha sheep manure (SM-1) applications had the highest values. Essential oil yield and fixed oil yield changed between 2.57-3.85 L/da and 16.18-36.90 L/da, respectively. The result of the study suggested that applications of SM-1 had the highest thousand fruit weight, fruit yield, essential oil yield, and fixed oil yield compared to other applications. PCA analysis showed the relationships among the examined properties, and component 1 and component 2 revealed 61.50% of the total variation of the valuables.

Conclusion: Sheep manure application (SM-1) can be used for the high fruit, essential oil, and fixed oil yield of fennel for sustainable agriculture.

Keywords: Essential oil yield, *Foeniculum vulgare* L., fixed oil yield, organic farming, PCA

Rezene Bitkisinde Kimyasal Gübre Yerine Organik Gübre Kullanımının Morfolojik ve Verime Etkisi Üzerine Araştırma

Öz

Amaç: Sürdürülebilir tarımsal üretim için kimyasal gübrelerin yerine alternatif bir yöntem olarak organik gübreler kullanılabilir. Koyun gübresi ve vermikompost en önemli alternatif uygulamalardır. Bu gübreler toprağın verimliliğini, bitki verimliliğini ve kalitesini artırabilir. Rezene (*Foeniculum vulgare* L.), insanlık tarihi boyunca tıbbi ve aromatik bir bitki olarak kullanılmış olup, gıda katkı maddesi, farmakolojik madde ve tıbbi uygulamalarda yaygın olarak kullanılmaktadır.

Materyal ve Yöntem: Bu çalışma, farklı organik gübreler (10, 15 ve 20 t/ha koyun gübresi (KG) ve vermikompost gübre (VG), kimyasal gübre (Amonyum sülfat (AS)-40, 80, 120 kg/ha) ve kontrol (gübresiz) uygulamalarının rezenenin morfolojisi, verimi ile uçucu yağ ve sabit yağ verimi üzerine etkilerini belirlemek amacıyla yürütülmüştür.

Araştırma Bulguları: Araştırmanın sonuçları, rezenenin sadece bitki boyu ve sabit yağ veriminde istatistiksel olarak önemli farklılıklar bulunduğunu göstermiştir. Meyve verimi 90.14 kg/da ile 122.72 kg/da arasında değişmekte olup, 80 kg/ha amonyum sülfat (AS-2) ve 10 t/ha koyun gübresi (KG-1) uygulamaları en yüksek değerleri vermiştir. Uçucu yağ verimi ve sabit yağ verimi sırasıyla 2.57-3.85 L/da ve 16.18-36.90 L/da arasında değişmiştir. Araştırma sonucunda KG-1 uygulamasının diğer uygulamalarla karşılaştırıldığında en yüksek bin meyve ağırlığı, meyve verimi, uçucu yağ verimi ve sabit yağ verimine sahip olduğu görülmüştür. PCA analizi incelenen özellikler arasındaki ilişkileri göstermiş ve bileşen 1 ve bileşen 2 değerleri toplam varyasyonunun %61.50'sini ortaya çıkarmıştır.

Sonuç: Sürdürülebilir tarım için rezenenin yüksek meyve, uçucu yağ ve sabit yağ verimi için koyun gübresi uygulaması (KG-1) kullanılabilir.

Anahtar Kelimeler: Uçucu yağ verimi, *Foeniculum vulgare* L., sabit yağ verimi, organik tarım, PCA

Introduction

Many plants have been used as medicinal sources throughout history. Plants of the Apiaceae family are one of the most important plants used in the medicine, food, pharmaceutical, and chemical industries. This family can be grown under moderate ecological conditions, and they are adapted to water scarcity stress (Omidbaigi, 2007). Fennel is one of the most popular medicinal and aromatic plants belonging to this family. Although it grows naturally in the Mediterranean climate zone, it can be cultivated in different parts of the world (Yaldiz and Camlica, 2022).

Fennel has been used for different purposes since ancient times. In folk medicine, it is used for balsamic, cardiotonic, digestive, galactagogue and tonic properties because it contains useful essential oil, phenolic, saponins, or etc. Essential oils and mature fruits are used in pharmaceutical products, cosmetics, and food products besides used as a functional food in human life (Saravanaperumal and Terza, 2012; Yaldiz and Camlica, 2022).

It is reported that the desired quality and quantity of fennel are preferred for the sustainable economic potential for the production and market (Yaldiz and Camlica, 2022). In this context, some agricultural systems, such as traditional agriculture, organic farming, and good agricultural applications, can be used to obtain high-yield and quality fennel production. Organic agriculture is one of the most available production systems for the reveal of healthy, non-toxic, and quality fennel fruits for people. Furthermore, adding organic fertilizer to the soil can enhance its physical and chemical properties. It can improve water retention capacity and provide essential nutrients such as nitrogen, phosphorus, potassium, calcium, and magnesium. Organic fertilizer contains a large amount of nutrients in a form that is easily absorbed by plants (Güneş et al., 2023).

Organic fertilization is an alternative approach to provide critical amounts of nutrients for crops within the framework of organic and sustainable agriculture, without negatively impacting crop yields or the environment (Chatzistathis et al., 2017). So, organic manures have supplementary nutrient sources for medicinal and aromatic plant cultivations and increase the morphological, yield, and chemical properties (Yaldiz et al., 2019a,b; Yaldiz and Camlica, 2023). Organic farming contributes to the agro-food chain and global market by contributing to more sustainable agriculture and safe food for the consumer (Yaldız and Çamlıca, 2018). Sheep manure (SM) is a nutrient-rich organic material that can be used as a soil amendment in agriculture. It can improve microbial activity, increase yield, and enhance growth parameters with quality properties (Paramesh et al., 2022). The sheep manure includes higher phosphorus and potassium elements than the other many manures from other animals (Souto et al., 2013). Vermicompost (VM) is produced through interactions between earthworms and microorganisms, resulting in the biooxidation and stabilization of organic material in a non-thermophilic process that contains finely divided mature peat-like material (Edwards and Burrows, 1988; Aira et al., 2007). Furthermore, the presence of a humic acid fraction in vermicompost makes it an efficient and eco-friendly organic amendment (Senesi et al., 1992). While vermicompost is better than traditional fertilization in terms of improving soil health, it is also important in terms of solid waste management.

In studies on SM and VM applications to have high quality and yield, these manures were recommended to be used at doses of 10 and 20 t/ha in dill (Meena et al., 2007), sugar beet (Pişkin, 2019), and common bean (Bucagu et al., 2017). VM doses were determined according to the previous studies (Bayram et al., 2021), the recommendations of the VM companies, and the suggestions of the fennel producers close to the experimental area.

The aim of the study is to estimate the fruit yield and yield components of fennel grown under different organic and inorganic fertilizer doses. So, the study tested the morphology and yield properties of fennel grown under different organic manures and chemical fertilizers. The results of the study can contribute to researchers understanding of fennel production.

Materials and Methods

Experiment location and design

The field study was conducted during the 2020 vegetation period (from April to September) at Tefenni District of Burdur (37° 18′ 34.2072″ N, 29° 46′ 28.9740″ E, 1163 m). The fruits of the fennel were obtained from the Tefenni District of Burdur, Türkiye, in the year 2020. In this study, AS (containing 21% nitrogen and 24% sulphur) and SM dose applications were determined as reported by previous studies (Meena et al., 2007; Bucagu et al., 2017). The SM was obtained from the rearing farm of a sheep production facility in Tefenni District of Burdur. Moreover, VM dose applications (obtained from Ekosol farm company) were applied according to previous studies and the suggestions of commercial companies (Bayram et al., 2021). The experiment was set up a site that had been without cultivation for a year. Before sowing, the soil in the experimental area was analyzed physically and chemically. The soil parameters were 23% clay, 61% sand, 16% silt, pH 8.10, EC 5.36 micromhos/cm, and contained 1.20% organic matter, 21 ppm P, 272 ppm K, 6382 ppm Ca, 1345 ppm Mg, and 5.05 ppm Fe. The average climatic data for the vegetation period was found to be 16.83 °C temperature, 29.8 mm rainfall, and 52.78% humidity (Çelik, 2023). The experiment was established in the open field in plots (1 × 4 m) of 4 rows of 40 × 20 cm. A complete randomized block design was used. Each application consisted of 3 replicates (plots), and each replicate contained 100 plants.

Treatments

The doses of sheep (10, 15, and 20 t/ha) and vermicompost (10, 15, and 20 t/ha) manures were applied 2 weeks before sowing in field conditions with a control (no fertilizer or manure) applications. Half of AS (20, 40, and 60 kg/ha) and a total of DAP (150 kg/ha) were applied at the sowing time. The remaining AS was added to the related plot before the flowering time. The agronomic applications were regularly applied to demonstrate good progress crop raising during the growing season. During the growing period, weed control and hoeing were carried out as necessary, without interruption. Drip irrigation was applied once or twice a week schedule and was controlled and adjusted weekly according to soil potential and daily climatic data from a weather station until the fruit setting time. Fennel fruit harvests were carried out in the first week of August 2020. Detailed information on used manures and fertilizer is given in Table 1.

Table1. Treatment code, description and application ratios of organic manures and chemical fertilizer

Code	Treatment description	Rate of application
Control	Control	Control
VM-1	Vermicompost	10 t/ha
VM-2	Vermicompost	15 t/ha
VM-3	Vermicompost	20 t/ha
SM-1	Sheep Manure	10 t/ha
SM-2	Sheep Manure	15 t/ha
SM-3	Sheep Manure	20 t/ha
AS-1	Ammonium sulphate, Diamonium phosfate	40 kg/ha AS and 150 kg/ha DAP
AS-2	Ammonium sulphate, Diamonium phosfate	80 kg/ha and 150 kg/ha DAP
AS-3	Ammonium sulphate, Diamonium phosfate	120 kg/ha and 150 kg/ha DAP

Sheep manure was applied as the first organic manure. The pH value of SM was 7.73, organic matter was 63.41%, EC was 6.05 micromhos/cm, and it contained 1.44% total N, 1.42% P, 1.89% K, 4.23% Ca, 0.74% Mg, and 0.14% Fe. Vermicompost manure was applied as a second manure. The pH value of VM was 8.40, organic matter 41.20%, EC 5.30 micromhos/cm, and contained 2.03% total N, 2.3% P, 1.5% K, 1.50% organic nitrogen, 10.70 C/N, and 28.80% moisture.

Essential oil isolation and yield calculation

The essential oil isolation of fennel fruits grown under SM, VM manures, and AS fertilizer was determined according to Yaldiz and Camlica (2022). The fennel fruits were dried at 35 ºC and ground with a grinder. Essential oil contents were determined volumetrically with the Clevenger apparatus according to the water distillation method of dried fruits.

Approximately 20 g of the dried plant seed prepared for analysis was weighed and placed in a glass Clevenger flask. Ten times (200 ml) of pure water was added to the sample, and it was subjected to hydro-distillation for approximately 4 hours. Then, the essential oil sample, which accumulated in the graduated section and formed a phase difference with water, was read, and the result was recorded in ml. The amount of essential oil was calculated as a percentage based on the weighing amount. After the determination of essential oil content as mL/100 g (%), the essential oil yield (L/da) was calculated using the following formula:

Essential oil yield (L/da) = Essential oil content (%)×Fruit yield (kg/da)

Isolation of fixed oil and yield calculation

The fixed oil of fennel fruits was determined and reported by Camlica and Yaldiz (2019). The fennel fruits were ground and dried at 76 ºC for 24 hours and analyzed in a soxhlet apparatus at 5 g each. After the fixed oil isolation, the fixed oil yield per decar was calculated using the following formula:

Fixed oil yield (kg/da): Fruit oil content (%) × Fruit yield (kg/da)

Statistical analysis

The study data were evaluated with an analysis of variance based on a completely randomized experimental design ($p<0.05$), and differences between AS, SM, and VM applications were evaluated using the Least Significant Difference test (LSD) in JMP 13. PCA analysis was also performed to determine the relationship between the examined properties using JMP 13. In addition, a heatmap was conducted using ClustVis (https://biit.cs.ut.ee/clustvis/).

Results

The effect of different manure types and doses on the morphological and yield properties is shown in Figure 1. Statistically significant differences were found for plant height among the manure doses. The plant height values ranged from 59.23 to 73.97 cm, with an average of 64.07 cm. The tallest plant height was found in the control application, followed by AS-3 and SM-1 organic manure doses. The smallest plant height was found in AS-1, followed by VM-3 and SM-3. The plant height values in organic manure applications decreased with increasing manure doses; however, increasing chemical fertilizer doses increased the plant height of fennel.

Statistically significant differences were not found among organic manure and chemical fertilizer applications in the experimental year with respect to the branch number (Figure 1). Branch number values were found in 3.23-3.60 number/plant in the vegetation periods. SM-1 and control applications showed the most branch numbers, and AS-1 and SM-2 had the least branch number values. SM and VM application doses showed differences on branch number, but AS applications from AS-1 to AS-3 increased the branch number of fennel. The average branch number of organic manures (SM and VM) was found to be higher than the average branch number of chemical fertilizer (AS).

The organic manure applications and chemical fertilizer on fennel were characterized by a high umbel number. The number of umbels in fennel was changed between 15.20 and 18.73, and it was found to be higher than 17 except for control and VM-2 applications (Figure 1). The highest number of umbels was found in the applications of VM-3 and SM-1 compared to the other applications. Also, the lowest number of umbels was found in the control application, followed by VM-2 and VM-1 applications. The third dose of AS, SM, and VM significantly increased the number of umbels in fennel compared to the second dose.

The umbellate number values per plant were found between 176.57 and 192.17, and no significant difference was found among the applications in fennel at the 5% level. While the highest number of umbellate values were found in VM-3 and VM-2, the lowest values were noted in SM-3 and control applications. Unlike the number of umbels, the averages of VM applications were found to be higher than those of applications (Figure 1).

The stem diameter of the fennel ranged from 6.47 to 7.50 mm when grown under organic manures and chemical fertilizer. The highest stem diameter was found in AS-1 and AS-3 applications, and the lowest values were obtained in VM-1 and SM-2 applications. The control applications were lower than the AS-1, AS-3, and SM-3 applications. Generally, averages of stem diameter values can be sorted AS> SM>VM (Figure 1).

Figure 1 shows the effects of organic manure and chemical fertilizer applications on the 1000 fruit weights of fennel. According to Figure 1, the highest results were found with the application of SM-1, AS-3, and AS-1. The lowest values were obtained from control and VM-3 applications. In this Figure, as the

VM application doses increased, the 1000 fruit weight decreased, while the increasing AS and SM applications showed fluctuating results from the least doses to high doses. The average values of the 1000 fruit weights were found to be higher in AS applications compared to other applications.

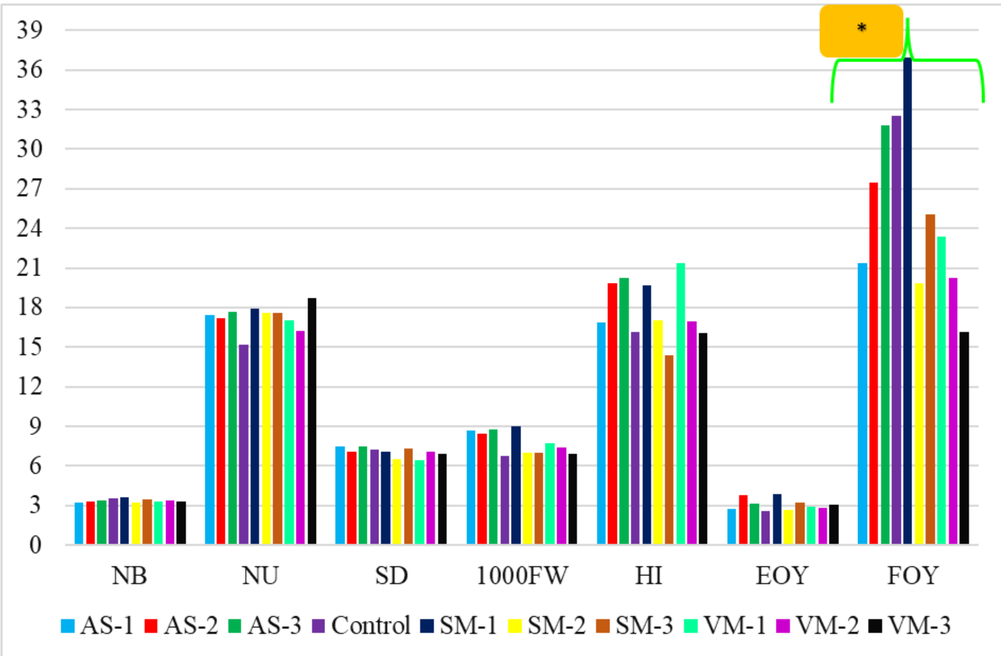
The effect of the SM, VM, and AS applications on the fruit yield of fennel in the vegetation period was statistically insignificant at the level of 5%. The highest fruit yields from the AS-2, SM1, and SM-3 applications were 122.72 kg/da, 118.11 kg/da, and 106.56 kg/da, respectively. The lowest fruit yields from the SM-2, VM-2, and VM-3 were 90.14 kg/da, 90.17 kg/da, and 90.44 kg/da, respectively. For VM application, a significant reduction was observed in the fruit yield; compared to the fruit yield obtained using AS and SM applications, VM applications produced less than 13.88 kg/da (13.17%) and 13.39 kg/da (12.76%) from the average fruit yield of AS and SM applications, respectively. Also, AS and SM applications showed a fluctuating trend among the applications, and VM applications showed a stable decreasing trend from VM-1 to VM-3 (Figure 1).

The biological yield values of the fennel changed between 493.33 kg/da and 775.00 kg/da grown under organic manures and chemical fertilizer. The highest biological yield values were found in SM-3 and control applications. VM-1 and AS-3 had the lowest biological yield values compared to other applications. The general averages of the SM manure were higher than those of AS and VM applications (Figure 1).

The results of the vegetation period indicated that different types and doses of organic manures and chemical fertilizer had statistically no significant effect on the harvest index of fennel (Figure 1). VM-1 and AS-3 recorded the highest harvest index, and SM-3 and VM-3 had the lowest harvest index values compared to other applications. The general averages of vermicompost and chemical fertilizer positively affected the harvest index, superior to the sheep manure.

No statistical differences were found for essential oil yield with increasing doses of organic manures and chemical fertilizer. Essential oil yield varied from 2.57 L/da to 3.85 L/da. The highest essential oil yield values were obtained in SM-1 and AS-2 applications, and the lowest values were obtained from the control and SM-2 applications (Figure 1). The general average essential oil yield increased by 2.91 l/da, 3.23 L/da, and 3.26 L/da in VM, AS, and SM applications, respectively. Sheep manure (especially SM-1) was the most effective organic manure for essential oil yield.

The analysis of the data contained in Figure 1 revealed that organic manures and chemical fertilizer doses were significant factors modifying the fennel fixed oil yield. The fixed oil yield ranged from 16.18 L/da to 36.90 L/da. The highest fixed oil yield was obtained using sheep manure at a dose of 10 t/ha (SM-1) and control applications. The lowest fixed oil yield values were obtained from VM-3, SM-2, and VM-2 applications. The highest average fixed oil yield value was found in the SM application, followed by the AS application.



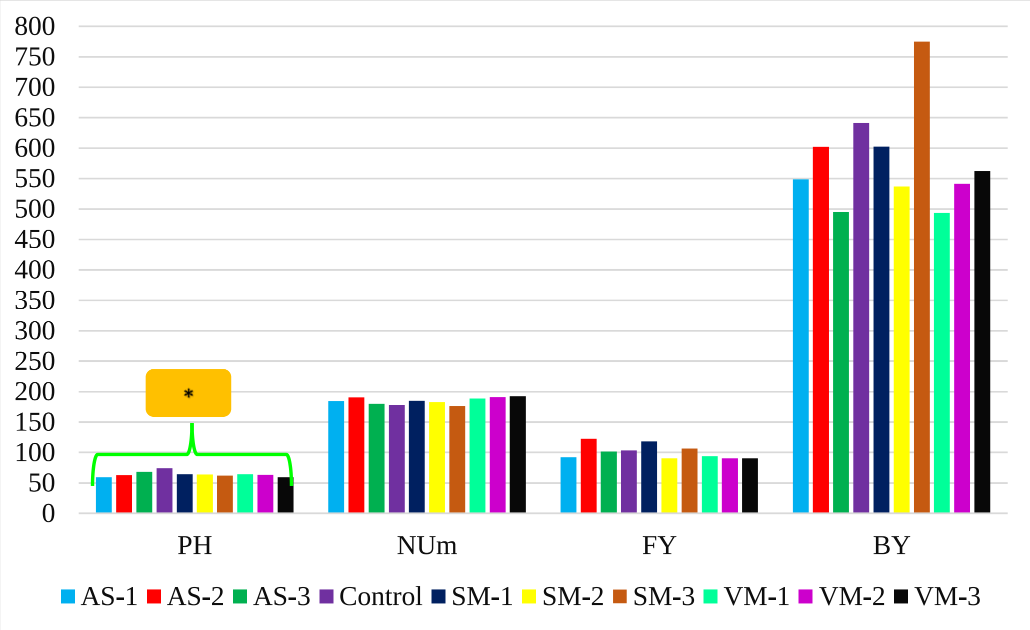


Figure 1. Morphology, yield and quality properties of fennel grown under organic manures and chemical fertilizer (AS: Ammonium sulphate, SM: Sheep manure, VM: Vermicompost, PH: Plant height, NB: Branch number, NU: Number of umbel, NUm: Number of umbellate, SD: Stem diameter, 1000 FW: 1000 fruit weight, FY: Fruit yield, BY: Biological yield, HI: Harvest index, EOY: Essential oil yield, FOY: Fixed oil yield, *: significant at $p<0.05$ level)

Principal coordinate analysis (PCA) was conducted to better understand the relationship among the examined properties in more detail (Figure 2). The results of PCA (Table 5) showed the first two principal components explained 61.50% of the total variation of the data. The first component explained 35.10% of the total variation, and the second component explained 26.40% of the total variation. The examined properties were divided into three groups, and the first group contained five properties (1000 fruit yield, fruit yield, harvest index, essential oil yield, and fixed oil yield). The second group contained four properties (plant height, branch number, stem diameter, and biological yield). The last group contained other properties (number of umbels and umbellates). Properties that are related to each other were included in the same groups. Eigen values were found to be higher than 1 in the first four values (Figure 2). In addition, the SM-1, AS-2, and AS-3 applications took place on the same side of the PCA, and these applications were found to have higher values in terms of the first group properties (Figure 2).

The contributions of the examined properties are given in Figure 3. Branch number, stem diameter, fruit yield, and fixed oil yield values were found to be the highest first contributions; number of umbellates, thousand fruit weight, and essential oil yield values were the second-highest contributions; and plant height, number of umbels, biological yield, and harvest index values were the last high contributions. Especially biological yield values were the most important contribution factors, followed by fixed oil yield, plant height, and 1000 fruit yield.

A comparative heat map analysis showed three different groups and clusters among the examined properties in this study (Figure 4). Group 1 consisted of the number of umbels and the number of umbellates. Fruit yield, essential oil yield, 1000 fruit yield, and harvest index were placed in group 2, and the rest of the examined properties, including plant height, branch number, fixed oil yield, stem diameter, and biological yield, were found in group 3. In a separate categorization of the growth, plants with control and SM-3 were grouped in cluster 1 (Figure 4). VM applications (VM-1, VM-2, and VM-3) showed lower values when SM-2 took place in the same cluster (cluster 2). AS applications with SM-1 were found in the same cluster (cluster 3). The highest plant height and biological yield values were found in cluster 1 or group 3. VM-1 and VM-3 had the highest harvest index and number of umbels, respectively, and these applications were the main sources of cluster 2 (Figure 4).

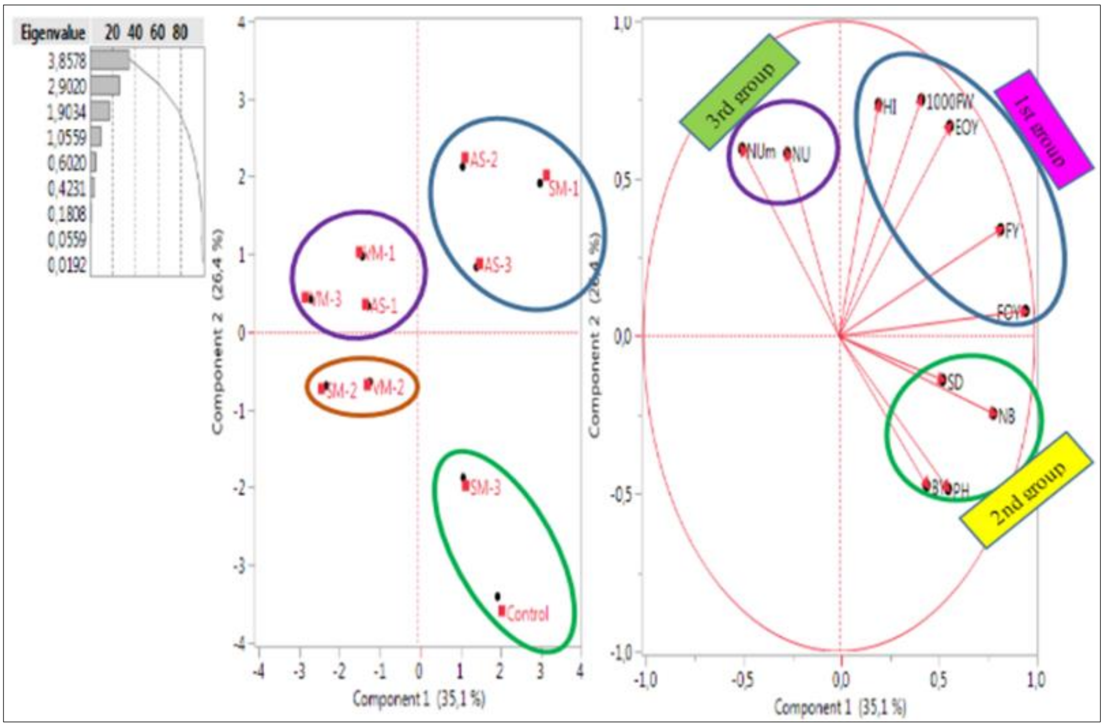


Figure 2. PCA analysis results of the examined properties (AS: Ammonium sulphate, SM: Sheep manure, VM: Vermicompost, PH: Plant height, NB: Branch number, NU: Number of umbel, NUm: Number of umbellate, SD: Stem diameter, 1000 FW: 1000 fruit weight, FY: Fruit yield, BY: Biological yield, HI: Harvest index, EOY: Essential oil yield, FOY: Fixed oil yield)

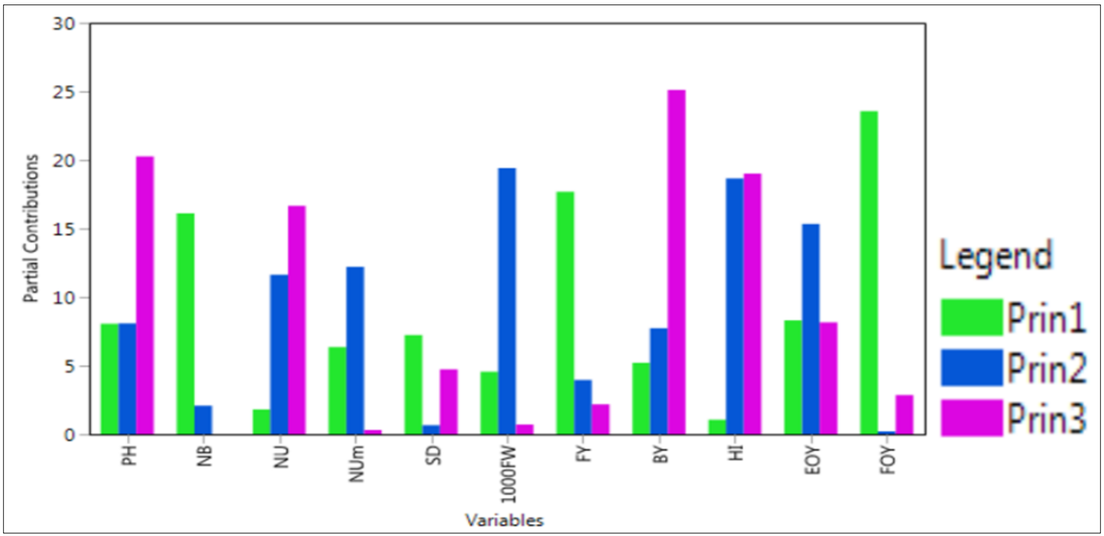


Figure 3. Examined properties contributions of fennel

The heatmap showed that plant height and biological yield values were found higher in control and SM-3 applications compared to other applications in group 3, respectively. The number of branches and fixed oil yield values were found higher at SM-1 applications in group 3. Especially the important properties as fruit yield and essential oil yield values were found in group 2, and the highest values were found at AS-2 and SM-1 applications. The umbels and umbellate values were peaked at VM-3 application in group 1. Furthermore, umbel and umbellate number values exhibited the lowest values at control and SM-3 applications. As a result of the Figure 4, SM-1 application can be suggested for the highest positive effect on the desired properties as fruit yield, essential oil yield and fixed oil yield of the fennel.

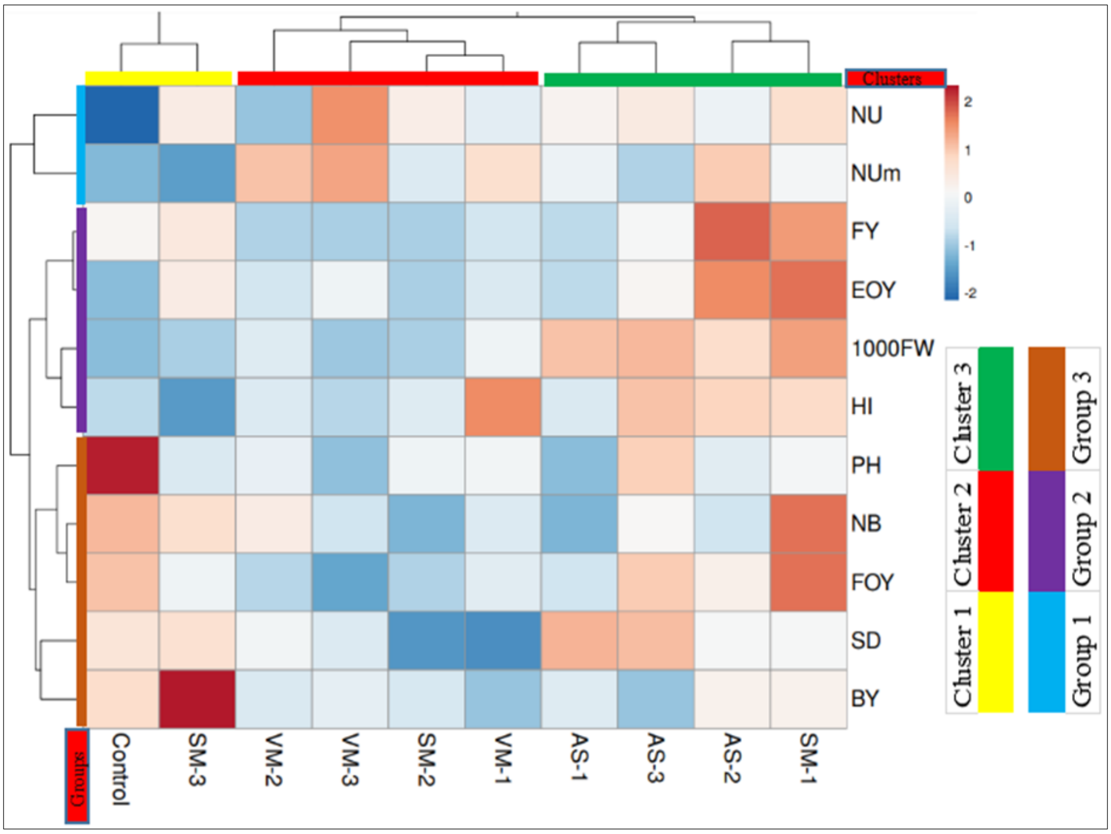


Figure 4. Heatmap and cluster analysis of the examined properties in fennel grown under organic manures (SM: Sheep manure, VM: Vermicompost, and chemical properties (AS: Ammonium sulfate, PH: Plant height, NB: Branch number, NU: Number of umbel, NUm: Number of umbellate, SD: Stem diameter, 1000 FW: 1000 fruit weight, FY: Fruit yield, BY: Biological yield, HI: Harvest index, EOY: Essential oil yield, FOY: Fixed oil yield). Additional details are shown in Figures 1-3.

Discussion

Organic manures are alternatives to contribute that plant nutrients and provide the long-term sustainability of agricultural ecosystems (Macik et al., 2020; Shaji et al., 2021). In addition, organic manures are environmentally friendly, increasing soil character and quality, protecting the soil fertility, protecting the loss of organic matter in short and long term, and preventing environmental harmfulness without causing plant productivity, and providing agricultural sustainability (Shaji et al., 2021). Similarly, Pavla and Pokluda (2008) reported that organic manures had positive impacts on plant growth, yield, quality properties and crop productivity associated with many activities, containing increases of the plant nutritional conditions.

The results of the analysis of variance revealed that there was a significant difference between organic manure and chemical fertilizer in terms of the plant height and fixed oil yield, and no significant statistical differences were found in other properties. Azzaz et al. (2009) reported that the supportive impacts of biological, organic manure, biological, and mineral fertilizations had positive results on the branch number of fennel. Lal (2008) reported that the different genotypes or vegetation periods can show large variability regarding economically important properties such as fruit yield, number of umbels, and umbellate of fennel. However, the present study showed that the examined properties of fennel revealed similar data. Although there was a difference between plant height and oil yield values, it can be said that organic manures and chemical fertilizer applications did not cause a wide variation between the examined properties. This can be explained by the genetic differences, applications, growth conditions, climatic data, and soil properties of the experimental area. Also, the used fennel genotype can be tolerant to organic manures and fertilizer, and the results showed that the soil physiology of the experiment area was sufficient in terms of organic matter and macro-micro mineral matter concentrations.

The fruit yield of the fennel can be affected by the umbel and umbellate numbers, either positively or negatively. The studies showed that increasing the number of umbel or umbellate values increased the fruit yield of fennel (Yaldiz and Camlica, 2022). Contrast to Yaldiz and Camlica (2022) report, the fruit yield of fennel showed differences regardless of the highest umbel and umbellate numbers.

In the studies on the morphology, yield, and essential oil yield of fennel, Özyılmaz (2015) reported that the number of umbrellas per plant changed between 20.14-36.52, fruit yield values between 149.3-261.6 kg/da, the thousand fruit weight 3.92-4.43 kg/da, biological yield 1431.4-2063.8 kg/da, and harvest index 18.3-21.0%. It was reported that the thousand fruit weight is desired to be high as it is associated with rapid germination and good plant development. It was also noted that the essential oil yield of fennel, which is an important feature in terms of usage area, varies between 2.60 and 4.68 kg/da.

Ehsanipour et al. (2012) conducted a study to determine the effects of different doses of nitrogen on the yield and quality of fennel. It was stated that applying nitrogen fertilization increased all yield and quality characteristics of fennel. The plant height was 176.9-220.4 cm, the number of umbels per plant was 40.4-75.1, the thousand fruit weight was 3.5-4.3 g, fruit yield was 49.77-133.02 kg/da. Nitrogen application increased the number of umbels per plant, plant height, thousand fruit weight, number of fruits per umbel, and fruit yield per decare.

Biofertilizer, organic fertilizer (rabbit manure), and mineral fertilizer (N, P, and K) were used to determine the effect on the morphology, yield, and quality properties of fennel. It was reported that the maximum content of NPK and rabbit manure increased the growth properties, bulb yield, bulb quality traits, and bulb essential oil (Nada et al., 2022).

In another study, Eisa (2016) reported that plant height changed between 61.92 and 75.71 cm and the number of umbrellas changed between 22.50 and 28.17. The application of 100% farmyard manure along with seaweed extract had an effect on the fresh and dry weight of the plant, plant height, number of branches, and fruit yield. It has been reported that the positive effect of farmyard manure on the number of umbels per plant may be related to improving the physical conditions of the soil, providing energy for the activity of microorganisms, and increasing the availability and uptake of nutrients.

Regarding the morphological and yield properties of the present study, a wide variation was observed in previous studies, which were close to the range reported for this plant by Yaldiz and Camlica (2022), Özyılmaz (2015), and Ehsanipour et al. (2012).

Many metabolic processes and secondary metabolites of medicinal and aromatic plants increase with mineral element availability (Janmohammadi et al., 2015). Also, nitrogen and phosphorus elements are needed for ATP and NADPH, which provide plant roots with lead-required nutrients for increasing essential oil content (Esmaielpour et al., 2017). In line with these references, the high essential oil yield was obtained from SM-1 and SM-3 with AS-2 and AS-3 applications because SM included high organic matter and AS was the nitrogen fertilizer. The VM contained 41.20% organic matter, and VM-3 had the highest essential oil yield compared to other VM applications. As a matter of fact, Yaldiz and Camlica (2023) reported that organic manures can be beneficial instead of chemical fertilizers because they have higher positive effects on the morphology, yield, and chemical properties of medicinal and aromatic plants.

Heatmap and PCA analyses clearly revealed that the applications of AS-2, AS-3, and SM-1 increased the yield and yield attribute values (Figures 2 and 4). The obtained results from this study show new insights into the examined properties triggered by organic manures and chemical fertilizer in fennel.

Conclusions

The present study shows the variability of the morphological, yield, and some quality properties of fennel grown under different organic manures and chemical fertilizers. Although there was no significant difference between inorganic and organic fertilizers, SM1, SM3, AS-2 and AS-3 stood out with respect of yield and yield parameters. In addition, the application of SM-1 increased EO and FO yield from fennel fruits compared to other applications. It should take into account the efficiency, the sustainability but also the cost of each inorganic and organic manures in order to make the best decision. The use of organic manures as an alternative to chemical fertilizers should be continued to protect the environment from pollution, reduce production costs, and produce a chemical-free product. The findings of the study suggest that the application of SM has promising effects on fennel fruit, EO and FO yield and can be considered as a suitable substitute for chemical fertilizers when growing fennel, a plant with increasing importance and demand.

Conflicts of Interest

The authors declare no conflicts of interest.

Authorship Contribution Statement

GY: Conceptualization, conceived the study, establishment and conducted of the experiment, carried out the field measurements, performed the statistical analysis, supervision, project administration, funding acquisition, writing-original draft preparation, writing-review and editing.

MÇ: Conducting analyses, investigation, methodology, writing-original draft preparation, writing-review and editing.

References

Aira, M., Monroy, F., & Dominguez, J. (2007). Earthworms strongly modify microbial biomass and activity triggering enzymatic activities during vermicomposting independently of the application rates of pig slurry. *Science of The Total Environment*, *385*, 252-261. https://doi.org/10.1016/j.scitotenv.2007.06.031

Azzaz, N. A. E., Hassan, E. A., & Hamad, E. H. (2009). The chemical constituent and vegetative and yielding characteristics of fennel plants treated with organic and bio-fertilizer instead of mineral fertilizer. *Australian Journal of Basic and Applied Sciences*, *3*, 579-587.

Bayram, C. A., Büyük, G., & Kaya, A. (2021). Effects of farm manure, vermicompost and plant growth regulators on yield and fruit quality in watermelon. *Journal of Agriculture and Nature*, *24(1)*, 64-69. https://doi.org/10.18016/ksutarimdoga.vi.701708

Bucagu, C., Ufitinema, B., Umutoniwabo, D., Niyitanga, F., & Karangwa, A. (2017). Effect of sheep manure and phosphorus fertiliser on productivity of snap bean (*Phaseolus vulgaris* L.) in Northern Rwanda. *Journal of Agriculture and Ecology Research International*, *12*(1), 1-9. https://doi.org/10.9734/JAERI/2017/32943

Camlica, M., & Yaldiz, G. (2019). Effect of cultural condition on seed growth and content of essential oil of two populations and one cultivar of genus Nigella. *Annals of Phytomedicine*, *8*(1), 56-62. http://dx.doi.org/10.21276/ap.2019.8.1.6

Chatzistathis, T., Papaioannou, A., Gasparatos, D., & Molassiotis, A. (2017). From which soil metal fractions Fe, Mn, Zn and Cu are taken up by olive trees (*Olea europaea* L., cv. 'Chondrolia Chalkidikis') in organic groves? *Journal of Environmental Management, 2017, 203*, 489-499.

Çelik, M. (2023). *Determination of nutritional contents of fennel harvest residues.* (Master Thesis, Department of Animal Science, Graduate School of Natural and Applied, Akdeniz University). https://tez.yok.gov.tr/UlusalTezMerkezi/tezSorguSonucYeni.jsp

Edwards, C. A., & Burrows, I. (1988). The potential of earthworm composts as plant growth media. C. A. Edwards and E. Neuhauser (Ed.), *In Earthworms in Waste and Environmental Management* (21-32 ss.). SPB Academic Press, The Hague, Netherlands.

Ehsanipour, A., Razmjoo, J., and& Zeinali, H. (2012). Effect of nitrogen rates on yield and quality of fennel (*Foeniculum vulgare* Mill.) accessions. *Industrial Crops and Products*, *35*(1), 121-125. https://doi.org/10.1016/j.indcrop.2011.06.018

Eisa, E.A. (2016). Effect of some different sources of organic fertilizers and seaweed extract on growth and essential oil of sweet fennel (*Foeniculum vulgare* Mill.) Plants. *Journal of Plant Production*, *7*(6), 575-584. https://doi.org/10.21608/JPP.2016.45528

Esmaielpour, B., Rahmanian, M., Heidarpour, O., & Shahriari, M. H. (2017). Effect of vermicompost and spent mushroom compost on the nutrient and essential oil composition of basil (*Ocimum basilicum* L.). *Journal of Essential Oil Bearing Plants, 20*(5), 1283-1292. https://doi.org/10.1080/0972060X.2017.1396931

Güneş, A., Keçe, Y.M., & Beyzi, E. (2023). The effects of using organic and chemical fertilizers on yield and yield parameters in different pepper (*Capsicum annuum* L.) varieties. *Gesunde Pflanzen, 75,* 1945-1952. https://doi.org/10.1007/s10343-022-00811-2

Janmohammadi, M., Sufi-Mahmoudi, Z., Ahadnezhad, A., Yousefzadeh, S., & Sabaghnia, N. (2015). Influence of chemical and organic fertilizer on growth, yield, and essential oil of dragonhead (*Dracocephalum moldavica* L.) plant. *Acta Agriculturae Slovenica*, *103*(1), 73-81. http://dx.doi.org/10.14720/aas.2014.103.1.08

Lal, R. K. (2008). Stability and genotypes × environment interactions in fennel. *Journal of Herbs, Spices and Medicinal Plants, 13*, 47-54.

Mącik M., Gryta A., & Frąc M. (2020). Biofertilizers in agriculture: An overview on concepts, strategies, and effects on soil microorganisms. In: Sparks D.L., (ed) Advances in Agronomy. Academic Press, 31-87.

Meena, S. S., Mehta, R. S., Malhotra, S. K., Singh, R. K., & Vashishtha, B. B. (2007). Effect of sheep manure, vermi-compost and bio-fertilizers on productivity of dill. *Indian Journal Arid Horticulture*, *2*(2), 29-30.

Nada, R. S., Ashmawi, A. E., Mady, E., Randhir, T. O., & Elateeq, A. A. (2022). Effect of organic manure and plant growth promoting microbeson yield, quality and essential oil constituents of fennel bulb (*Foeniculum vulgare* Mill.). *Journal of Ecological Engineering*, *23*(5), 149-164. https://doi.org/10.12911/22998993/147252

Omidbaigi, R. (2007). Production and processing of medicinal Plants. Tarbiat Modares University Press, Tehran, 2007.

Özyılmaz, B. (2015). *Farklı yörelerden temin edilen tatlı rezene (Foeniculum vulgare var. dulce) populasyonlarının karakterizasyonu.* (Doktora tezi, Gaziosmanpaşa Üniversitesi Fen Bilimleri Enstitüsü Tarla Bitkileri Anabilim Dalı Doktora Tezi, Tokat). https://tez.yok.gov.tr/UlusalTezMerkezi/tezSorgu SonucYeni.jsp

Paramesh, V., Ravisankar, N., Behera, U., Arunachalam, V., Kumar, P., Rajkumar, S. R., Dhar Misra, S., Kumar, M. R., Prusty, A. K., Jacob, D., & Panwar, A. S. (2022). Integrated farming system approaches to achieve food and nutritional security for enhancing profitability, employment, and climate resilience in India. *Food and Energy Security*, *11*(2), 321. https://doi.org/10.1002/fes3.321

Pavla, B., & Pokluda, R. (2008). Influence of alternative organic fertilizers on the antioxidant capacity in head cabbage and cucumber. *Notulae Botanicae Horti Agrobotanici Cluj*, *36*, 63-67.

Pişkin, A. (2019). The effect of sheep manure on yield and quality in production of organic sugarbeet. *Israel Journal of Plant Sciences*, *66*(3-4), 238-242.

Saravanaperumal, S. A., & Terza, A. L. (2012). Polyphenolics free DNA isolation and optimization of PCRRAPD for fennel (*Foeniculum vulgare* Mill.) from Mature and Young Leaves. *African Journal of Biotechnology*, *11,* 8622-8631. http://doi.org/10.5897/AJB11.1676

Senesi, N., Saiz-Jimenez, C., & Miano, T.M. (1992). Spectroscopic characterization of metal-humic acid-like complexes of earthworm-composted organic wastes. *Science of The Total Environment, 117-118*, 111-120. https://doi.org/10.1016/0048-9697(92)90079-8

Shaji H., Chandran V., & Mathew L. (2021). Organic fertilizers as a route to controlled release of nutrients. F. B., Lewu, T., Volova ve S. K. R. R. Thomas (ed.), *Controlled Release Fertilizers for Sustainable Agriculture* (231-245 ss.). Academic Press.

Souto, P.C., Souto, J.S., & do Nascimento, J.A.M. (2013). Liberation of nutrients during the decomposition of different in luvis-solo in the semiarid paraibano. *Revista Caatinga*, *26*, 69-78.

Yaldız, G., & Çamlıca, M. (2018). Production and trade of medical and aromatic plants in Turkey. *Bahçe, 47*(sp. 2), 224-229.

Yaldiz, G., & Camlica, M. (2022). Breeding improvement of fennel genotypes of different origins (*Foeniculum vulgare* L.) using morphological and yield parameters. *International journal of Agriculture and Natural Resources, 49*(2)*,* 97-111. http://dx.doi.org/10.7764/ijanr.v49i2.2345

Yaldiz, G., & Camlica, M. (2023). Assessing the effect of various doses of organic manures on herbage yield, essential oil, and compositions of sage grown under climate chamber and field conditions. *Organic Agriculture*, *13*, 377-397. https://doi.org/10.1007/s13165-023-00434-5

Yaldiz, G., Camlica, M., & Ozen, F. (2019a). Biological value and chemical components of essential oils of sweet basil (*Ocimum basilicum* L.) grown with organic fertilization sources. *Journal of the Science of Food and Agriculture*, *99,* 2005-2013. https://doi.org/10.1002/jsfa.9468

Yaldiz, G., Camlica, M., & Ozen, F. (2019b). The effects of organic fertilizer on yield and quality properties of medicinal plants*. International Anatolian Journal of Agricultural Engineering Sciences*, *1*(3), 37-48.