Archives of Agriculture Sciences Journal
Print ISSN: 2535-1680
Online ISSN: 2535-1699

ARCHIVES OF AGRICULTURE SCIENCES JOURNAL
Volume 8, Issue 2, 2025, Pages 131–161
Available online at https://aasj.journals.ekb.eg
DOI: https://dx.doi.org/10.21608/aasj.2025.457748

Effects of plant density, mineral fertilization and effective microorganisms on the development and essential oil yield of *Ocimum basilicum* L.

Mahmoud A. A.[a*], and Fouad Fatma A.[b]

[a]*Department of Horticulture, Faculty of Agriculture, Al-Azhar University, Assiut, Egypt*
[b]*Central Laboratory of Organic Farming, Agricultural Research Center, Giza, Egypt*

Abstract

This study examined the impacts of plant density, mineral fertilizers (NPK), biological fertilizers (effective microorganisms, EM), and their interactions on the growth, essential oil content, and chemical composition of sweet basil (*Ocimum basilicum* L.) using a split-plot design with three replicates. The main factor consisted of three plant density levels: high, medium, and low (90, 60, and 42 plants/10.8 m², equivalent to 33333, 22222 and 15555 plants/feddan, respectively). The secondary factor included five fertilizer treatments: the full NPK recommended dose (100%), EM alone, and combinations of 75%, 50%, and 25% NPK with EM. Results showed that lower plant density enhanced per-plant traits, including branch number, herb and leaf dry weights per cut, seasonal yield per plant, and NPK percentages in dried leaves, but reduced plant height. Conversely, the highest density maximized herb and leaf dry weight yields per feddan = (4200 m^2). Essential oil yield per plant per season increased at lower density, while oil yield per fed decreased. The 75% NPK + EM and 100% NPK treatments produced the highest plant height, branch number, dry weights, seasonal yield per plant, and essential oil content across all three cuts during both seasons. The optimal combination for growth parameters, essential oil percentage, oil yield per plant, and NPK percentages in dried leaves was the lowest density (42 plants/10.8 m²) with 75% NPK + EM, while the highest essential oil yield per feddan was achieved with the highest density (90 plants/10.8 m²) combined with 75% NPK + EM.

Keywords: Sweet basil, plant density, effective microorganisms, NPK, essential oil.

*Corresponding author: Mahmoud A. A.,
E-mail address: ahmedali777777111@gmail.com

1. Introduction

According to the World Health Organization (2008), approximately 80% of the global population depends on medicinal and aromatic plants for their therapeutic properties, which include bioactive compounds like phenols, tannins, alkaloids, glycosides, saponins, and secondary metabolites (Naguib, 2011). *Ocimum basilicum* L is a herbaceous plant from the Lamiaceae family, the most economically significant species within the diverse Ocimum genus, valued for its volatile oil, fresh or dried herbs, and ornamental qualities (El-Gendy *et al*., 2001). Typically growing to 50 cm, or over one meter under favorable conditions, sweet basil features glossy, oval leaves, square stems, and small white bilabiate flowers in dense spikes, with fine black seeds (USDA, 2008). It is a rich source of bioactive compounds, including monoterpenes, sesquiterpenes, and phenylpropanoids (e.g., linalool, eugenol, estragole, and methyl chavicol), which provide antioxidant, antitussive, diuretic, anthelmintic, tranquilizing, and expectorant properties (Dzida, 2010; Ekren *et al*., 2012; Esetili *et al*., 2016; Sharafzadeh and Alizadeh, 2011). The essential oil, constituting up to 1.5% of the plant, is used to treat conditions such as dental issues, respiratory disorders, fungal infections, and digestive problems, while also providing nutritional benefits, including 22 calories per 100 grams, carbohydrates, fiber, protein, fats, and minerals like calcium, potassium, and iron (Andrea *et al*., 2007; Telci *et al*., 2006). Plant spacing is a crucial determinant of yield and quality in sweet basil (*Ocimum basilicum* L.) cultivation, as it affects aeration, light penetration, and photosynthetic efficiency. Optimal spacing maximizes resource utilization (water, air, light, and nutrients) while minimizing competition, thereby enhancing crop productivity (Abbas, 2014; Atghaei *et al*., 2015; Bekhradi *et al*., 2014; Chegini *et al*., 2012; Sadeghi *et al*., 2009). Inadequate nutrition, particularly deficiencies in nitrogen, phosphorus, and potassium, poses significant challenges to basil production under typical agroclimatic conditions. Research indicates that plant density significantly influences dry matter and essential oil yield, underscoring the importance of determining appropriate spacing to optimize basil cultivation outcomes (Dadvand *et al*., 2009; Khafi, 2003;). Plant fertilization with essential macronutrients, nitrogen (N), phosphorus (P), and potassium (K), are critical for sweet basil production. Numerous studies have shown that increasing NPK fertilizer levels enhances mineral uptake in plants. However, the continuous application of chemical fertilizers contributes to environmental pollution and undermines the sustainability of agricultural systems (Bagali *et al*., 2012). In Egypt, the common practice among farmers of applying excessive fertilizers to boost productivity has led to a significant environmental and health concerns, including ecosystem degradation, atmospheric pollution, and risks to human health (Mostafa *et al*., 2021). Additionally, the overuse of chemical fertilizers escalates production costs and accelerates soil fertility decline. Consequently, there is an urgent need to explore alternative, safe, and natural sources of plant nutrients, alongside sustainable approaches to enhance crop productivity and ensure food security. Biological fertilization using effective microorganisms (EM) enhances crop yield, soil mineral availability, and essential oil content in aromatic plants while reducing dependence on inorganic fertilizers. EM, a commercial microbial blend, includes photosynthesizing bacteria, actinomycetes, lactic acid bacteria, yeasts, and fermenting fungi like aspergillus and penicillium, with specific strains such as *Streptomyces albus* (10^5 cell/ml), *Propionibacterium freudenreichii* (10^5 cell/ml), *Streptococcus lactis* (10^5 cell/ml), *Aspergillus oryzae* (10^5 cell/ml), *Mucor hiemalis* (10^5 cell/ml), *Saccharomyces cerevisiae* (10^5 cell/ml), and *Candida utilis* (10^5 cell/ml), alongside unspecified amounts of *Lactobacillus sp*., *Rhodopseudomonas sp*., and *Streptomyces griseus* (Formowitz *et al*., 2007; Muthaura *et al*., 2010; Wielgosz *et al*., 2010). Research on crops like cotton, maize, sweet potatoes, rice, triticale, wheat, and horticultural species such as roses and apples confirm EM positive impact on plant performance, though Mayer *et al*. (2010) noted no significant yield improvements in some instances (Boligłowa and Gleń, 2008; Górski and Kleiber, 2010; Eissa, 2002; Klama and Kleiber, 2010; Kengo and Hui-lian, 2000; Khaliq *et al*., 2006; Sahain *et al*., 2007; Shah *et al*., 2001). EM promotes soil microflora proliferation, nutrient availability, and plant growth by fostering favorable microbial conditions, with efficacy influenced by soil fertility, plant species, climate, and ecological factors (Higa, 2003; Janas, 2009; Wielgosz *et al*., 2010). The primary aim of this study was to investigate the impact of plant density on maximizing herb and essential oil yields of sweet basil (*Ocimum basilicum*) under the environmental conditions of Assiut Governorate. Additionally, the study sought to minimize or eliminate the use of mineral fertilizers by exploring the potential of biofertilizers as a partial or complete substitute. This approach addresses the adverse health impacts and high costs associated with mineral fertilizers.

2. Materials and methods

2.1 Experimental site and treatments description

This research assessed the effects of plant density, mineral fertilizers (N, P and K), and biological fertilizers (effective microorganisms, EM), along with their interactions, on the growth, yield, essential oil production, and chemical composition of sweet basil (*Ocimum basilicum* L.) across two summer growing seasons (2023 and 2024). The experiments were conducted at the agricultural farm of the Faculty of Agriculture, Al-Azhar University, Assiut

Branch, Egypt (27° 12⁻ 16.67= N latitude and 31° 09⁻ 36.86= E longitude). The study employed a completely randomized block design with a split-plot arrangement, comprising three replicates. Three plant density levels were assigned to the main plots, while five fertilizer treatments were allocated to the subplots, resulting in 15 treatment combinations, each replicated three times to ensure robust statistical analysis. Sweet basil seeds, sourced from the Agricultural Research Center in Giza, were sown in a nursery on March 15th of each season. Seedlings were transplanted 45 days later (April 29^{th}) into plots measuring 3.0 × 3.6 m (10.8 m^2), arranged in six rows spaced 60 cm apart. Basil seedlings were planted in hills with inter-hill spacing's of 20, 30, and 40 cm, corresponding to 90, 60, and 42 plants per plot, equivalent to plant densities of 33333, 22222, and 15555 plants per fed, respectively.

2.2 Soil analysis

The physical and chemical properties of the soil used in both seasons (averaged across the two seasons) were analyzed following the methods outlined by Jackson (1973). The soil exhibited a clay texture, with a composition of 19.4% sand, 27.2% silt, and 53.4% clay. The soil pH was 7.61 (measured in a 1:2.5 soil-to-distilled water suspension), with an electrical conductivity (EC) of 1.03 dS/m (in a 1:5 soil solution). The soil contained 1.97% total $CaCO_3$, 0.97% organic matter, 0.70% total nitrogen and 0.21% total phosphorus. Soluble ions in the soil paste (meq/L) included Cl^- (3.39), HCO_3^- (4.19), SO_4^{2-} (3.05), Ca^{2+} (4.87), Mg^{2+} (0.52), Na^+ (1.38), and K^+ (3.86).

2.3 Treatments

Main Plots (A): consists of three plant densities as follows: 90 plants per 10.8 m^2, equivalent to 33333 plants per feddan (20 cm spacing between plants, 15 plants per row), 60 plants per 10.8 m^2, equivalent to 22222 plants per feddan (30 cm spacing between plants, 10 plants per row) and 42 plants per 10.8 m^2, equivalent to 15555 plants per feddan (40 cm spacing between plants, 7 plants per row). Subplots (B): comprised five fertilizer treatments as follows: 100% of the recommended dose (RD) of NPK, biofertilizer (effective microorganisms, EM) without NPK, 75% NPK RD + EM, 50% NPK RD + EM and 25% NPK RD + EM. NPK Fertilizers: Three NPK fertilizer rates were applied: 100%, 50%, and 25% of the recommended dose. The full recommended dose (100%) consisted of 300 kg /$feddan^{-1}$ ammonium sulphate (20.5% N), 250 kg /$feddan^{-1}$ calcium superphosphate (15.5% P_2O_5) and 200 kg/ $feddan^{-1}$ potassium sulphate (48.5% K_2O). Calcium superphosphate was incorporated into the soil during preparation as a single application for each rate. Ammonium sulphate and potassium sulphate were combined and applied in three equal doses: the first on April 29^{th} (transplanting date), the second one month after transplanting, and the third after the first herb cut on July 7^{th}, for each rate. Effective Microorganisms (EM): comprising photosynthetic and nitrogen-fixing bacteria, were sourced from the Ministry of Environment, Egypt. Each 1 ml of EM contained 10^7 active bacterial cells. The EM solution was prepared at a concentration of 50 ml EM diluted in 500 ml water and applied at 50 ml per plant to the soil near the plant base. Three applications were applied: 2 weeks after transplanting, 8 days after the first herb cut and one week after the second herb cut during both growing seasons. Plants were irrigated immediately following each application. All treatments adhered to standard agricultural practices. The composition of effective microorganisms (EM), as detailed in Table (1), is based on established formulations described by Daly and Stewart (1999) and Higa (2004).

Table (1): Composition of effective microorganisms (EM) used in the study.

Bio strains	Types
Actinomycetes	*Streptomyces albus; Streptomyces griseus*
Yeasts	*Saccharomyces cerevisiae; Candida utilis*
Photosynthetic bacteria	*Rhodopseudomonas palustrus; Rhodobacter spaeroides*
Fermenting fungi	*Aspergillus oryzae; Mucor hiemalis*
Lactic acid bacteria	*Lactobacillus plantarum; Lactobacillus casei; Streptococcus lactis*

2.4 Harvesting Times

In each experimental season, sweet basil plants were harvested three times at approximately 50% flowering. For each harvest, plants were cut, leaving approximately 10 cm of stem above the soil surface. The harvests were conducted on July 1st, August 14th, and September 29th during both summer growing seasons.

2.5 Data Recorded

2.5.1 Vegetative growth parameters

The following parameters were measured at each harvest: Plant height (cm), number of branches per plant per cut, herb dry weight per plant per cut (g)/plant, leaf dry weight per plant per cut (g)/plant, additionally, the following vegetative growth metrics were calculated: Total herb dry weight (g)/plant/season, total herb dry yield (ton)/fed/season, total leaf dry weight (g)/plant/season and total leaf dry yield (ton)/feddan/season.

2.5.2 Essential oil production

The essential oil percentage was determined from random air-dried herb samples for each treatment at every cut during both seasons, following the method outlined in the British Pharmacopoeia (1963). This involved distilling 60 g of herb for 3 hours to extract the essential oil, with yields calculated as ml/plant/cut, ml/plant/season, and l/feddan/season.

2.5.3 Chemical constituents

The N, P and K percentages in the dried leaf samples from the third cut were analyzed using methods described by Horneck and Miller (1998) for nitrogen, Sandell (1950) for phosphorus, and Horneck and Hanson (1998) for potassium.

2.6 Statistical analysis

All data related to growth, essential oil production, and chemical composition were subjected to statistical analysis using Statistic version 9 (Statistix, 2008), following the methodology of Mead *et al.* (1993). Mean comparisons were conducted using the least significant difference (LSD) test at a 5% significance level.

3. Results

3.1 Vegetative growth traits

3.1.1 Plant height (cm)

3.1.1.1 Impact of plant density

Plant density significantly affected plant height across all three cuts during 2023 and 2024 growing seasons. The highest density (90 plants/10.8 m²) resulted in the tallest plants, recording heights of 53.0, 56.6 and 58.7 cm in the 1st, 2nd and 3rd cuts, respectively of the 2023 season, and 54.7, 57.5 and 60.6 cm in the corresponding cuts, respectively of the 2024 season. The medium density (60 plants/10.8 m²) produced plants with heights of 50.8, 54.2 and 56.1 cm in 2023 and 52.4, 55.3 and 58.4 cm, respectively in 2024. The lowest density (42 plants/10.8 m²) yielded the shortest plants, with heights of 49.4, 52.5 and 54.3 cm in 2023, and 50.6, 53.4 and 56.5 cm, respectively in 2024 (Table 2). No significant differences were found between the 60 and 42 plants/10.8 m² density levels in the first cut of the 2023 season.

3.1.1.2 Impact of fertilizer treatments

Data presented in Table 2 demonstrate that all fertilizer treatments combining NPK and effective microorganisms (EM) significantly improved plant height across all three cuts in both the 2023 and 2024 seasons, except the comparison between 100% NPK and 50% NPK + EM in the first cut of 2023, where no significant difference was observed. Among the five fertilizer treatments, the combination of 75% NPK recommended dose with EM yielded the tallest plants, recording heights of 56.9, 60.3, and 62.2 cm in the first, second, and third cuts of 2023, respectively, and 58.4, 61.5, and 64.6 cm in the corresponding cuts of 2024. Conversely, treated plants with EM only exhibited the lowest plant height values across all three cuts in both seasons.

3.1.1.3 Interaction between plant density and fertilizer treatments

The interaction between plant density and fertilizer treatments had a significant influence on plant height through all three cuts in both seasons (Table 2). The tallest plants were observed in the higher density treatments (90 and 60 plants/plot) combined with 75% NPK RD + EM, yielding heights of 58.7 and 56.9 cm in the 1st cut, 62.3 and 60.6 cm in the 2nd cut, and 64.3 and 62.6 cm in the 3rd cut of 2023, and 60.5 and 58.8 cm, 63.5 and 61.8 cm, and 66.6 and 64.9 cm in the first, second, and third cuts of 2024, respectively.

Table (2): Impact of plant density, NPK and EM treatments and their interactions on plant height of sweet basil *(Ocimum basilicum* L.*)* during 2023 and 2024 seasons.

Treatments (B)	Plant densities per 10.8 m^2 (A)							
	2023 season				2024 season			
	90	60	42	Mean (B)	90	60	42	Mean (B)
	1st Cut							
100% NPK$_{RD}$	54.9	52.6	50.8	52.8	55.7	54.3	52.0	54.0
EM without NPK	46.9	45.4	44.3	45.5	48.8	46.9	45.7	47.1
75% NPK$_{RD}$ + EM	58.7	56.9	54.9	56.9	60.5	58.8	56.1	58.4
50% NPK$_{RD}$ + EM	53.6	50.4	49.5	51.2	55.5	52.1	50.3	52.7
25% NPK$_{RD}$ + EM	51.1	48.4	47.6	49.0	53.2	49.8	48.8	50.6
Mean (A)	53.0	50.8	49.4		54.7	52.4	50.6	
LSD 0.05	A: 2.1 B: 1.7 AB: 3.0				A: 1.6 B: 1.3 AB: 2.2			
	2nd Cut							
100% NPK$_{RD}$	57.6	56.1	53.9	55.9	58.8	57.3	55.1	57.1
EM without NPK	50.7	48.8	47.6	49.0	51.9	49.3	48.8	50.0
75% NPK$_{RD}$ + EM	62.3	60.6	58.0	60.3	63.5	61.8	59.2	61.5
50% NPK$_{RD}$ + EM	57.4	54.0	52.2	54.5	57.9	55.2	53.4	55.5
25% NPK$_{RD}$ + EM	55.0	51.7	50.7	52.5	55.5	52.9	50.5	53.0
Mean (A)	56.6	54.2	52.5		57.5	55.3	53.4	
LSD 0.05	A: 1.6 B: 1.3 AB: 2.2				A: 1.8 B: 1.4 AB: 2.4			
	3rd Cut							
100% NPK$_{RD}$	59.5	58.1	55.8	57.8	61.9	60.4	58.2	60.2
EM without NPK	52.3	50.7	49.5	50.9	55.0	52.3	51.9	53.1
75% NPK$_{RD}$ + EM	64.3	62.6	59.7	62.2	66.6	64.9	62.3	64.6
50% NPK$_{RD}$ + EM	60.2	55.7	54.1	56.6	61.0	58.3	56.5	58.6
25% NPK$_{RD}$ + EM	57.0	53.5	52.5	54.3	58.6	56.0	53.6	56.1
Mean (A)	58.7	56.1	54.3		60.6	58.4	56.5	
LSD 0.05	A: 1.3 B: 1.1 AB: 1.9				A: 1.8 B: 1.3 AB: 2.3			

3.1.2 Number of branches per plant per cut

3.1.2.1 Impact of plant density

The results indicated that plant density significantly influenced the number of branches per plant per cut (Table 3). The number of branches increased progressively as plant density decreased, with significant differences observed among density treatments across all three cuts in both the 2023 and 2024 seasons. The lowest plant density (42 plants/ plot) produced the highest branch counts, recording 20.2 and 20.3 branches/plant in the first cut, 22.7 and 23.7 in the second cut and 25.0 and 28.2 in the third cut for the 2023 and 2024 seasons, respectively.

3.1.2.2 Impact of fertilizer treatments

All five fertilizer treatments significantly enhanced the number of branches per plant across all three cuts in the 2023 and

2024 seasons (Table 3). The combination of 75% NPK recommended dose (RD) + effective microorganisms (EM) produced the highest branch counts, recording 21.4 and 21.3 branches/plant in the first cut, 23.7 and 24.7 in the second cut, and 26.1 and 29.5 in the third cut for the 2023 and 2024 seasons, respectively, surpassing all other treatments. The 100% NPK treatment followed, yielding 18.9 and 18.7 branches/plant in the first cut, 21.1 and 22.0 in the second cut, and 23.6 and 26.7 in the third cut for the respective seasons. No significant differences were observed between 100% NPK and 50% NPK + EM, or between EM alone and 25% NPK + EM, in the first and third cuts of both seasons, nor between 100% NPK and 50% NPK + EM, or EM alone and 25% NPK + EM, in the second cut of the 2024 season. Regardless of other treatments, the lowest branch counts were recorded for the EM-only treatment in both seasons across all three cuts.

3.1.2.3 Interaction between plant density and fertilizer treatments

The interaction between plant density and fertilizer treatments (A×B) significantly affected the number of branches per plant across all three cuts in both seasons (Table 3). The most effective combination was observed with the lowest plant density (42 plants/ plot) paired with 75% NPK RD + EM, resulting in the highest branch counts.

Table (3): Impact of plant density, NPK and EM treatments and their interactions on number of branches of sweet basil (*Ocimum basilicum* L.) during 2023 and 2024 seasons.

Treatments (B)	Plant densities per 10.8 m^2 (A)							
	2023 season				2024 season			
	90	60	42	Mean (B)	90	60	42	Mean (B)
	1st Cut							
100% NPK_{RD}	51.3	54.8	62.7	56.3	53.0	56.3	64.2	57.8
EM without NPK	46.3	47.7	55.7	49.9	47.4	49.3	57.2	51.3
75% NPK_{RD} + EM	55.3	57.3	64.6	59.1	57.1	58.8	66.1	60.7
50% NPK_{RD} + EM	49.1	51.8	61.2	54.1	50.6	53.3	62.7	55.5
25% NPK_{RD} + EM	47.5	50.3	57.8	51.9	49.1	52.2	59.5	53.6
Mean (A)	49.9	52.4	60.4		51.4	54.0	61.9	
LSD 0.05	A: 1.4 B: 2.9 AB: 4.9				A: 1.6 B: 2.8 AB: 4.9			
	2nd Cut							
100% NPK_{RD}	57.7	61.0	68.9	62.5	57.8	61.3	69.1	62.8
EM without NPK	52.1	54.0	61.9	56.0	52.3	54.2	62.1	56.2
75% NPK_{RD} + EM	61.8	63.5	70.8	65.4	61.9	63.8	71.1	65.6
50% NPK_{RD} + EM	55.3	58.0	67.4	60.2	55.6	58.2	67.6	60.5
25% NPK_{RD} + EM	53.8	56.9	64.2	58.3	54.1	57.1	64.5	58.5
Mean (A)	56.1	58.7	66.6		56.3	58.9	66.9	
LSD 0.05	A: 1.6 B: 2.8 AB: 4.9				A: 1.7 B: 2.7 AB: 4.8			
	3rd Cut							
100% NPK_{RD}	64.0	67.3	75.1	68.8	62.5	66.0	73.7	67.4
EM without NPK	58.4	60.2	68.1	62.2	57.1	59.0	66.7	60.9
75% NPK_{RD} + EM	68.1	69.7	77.1	71.6	66.7	68.4	75.9	70.3
50% NPK_{RD} + EM	61.5	64.2	73.6	66.4	60.4	63.0	72.4	65.3
25% NPK_{RD} + EM	60.0	63.1	70.4	64.5	58.7	61.9	69.1	63.2
Mean (A)	62.4	64.9	72.8		61.1	63.7	71.5	
LSD 0.05	A: 1.7 B: 2.9 AB: 5.0				A: 1.6 B: 2.8 AB: 4.9			

3.1.3 Herb and leaf dry weights (g/plant/cut)

3.1.3.1 Impact of plant density

Data presented in Tables (4 and 5) indicate that plant density influenced herb and leaf dry weights (g)/plant/cut across all three cuts in both the 2023 and 2024 growing seasons. The lowest plant density (42 plants/plot) yielded the highest herb dry weights, recording 60.4 and 61.9 g/plant in the first cut, 66.6 and 66.9 g/plant in the second cut, and 72.8 and 71.5 g/plant in the third cut for the 2023 and 2024 seasons, respectively (Table 4). Similarly, the highest leaf dry weights were observed at this density, with values of 25.9 and 28.1 g/plant in the first cut, 31.4 and 32.8 g/plant in the second cut, and 37.6 and 37.3 g/plant in the third cut for both seasons, respectively (Table 5). No significant differences were noted between the 90 and 60 plants/10.8 m² density levels in the third cut of the 2023and 2024 seasons for leaf dry weight g/plant/cut.

3.1.3.2 Impact of fertilizer treatments

Herb and leaf dry weights (g/plant/cut) were significantly increased by the application of NPK and effective microorganism (EM) fertilizer treatments. The combination of 75% NPK recommended dose + EM consistently yielded the highest herb and leaf dry weights across all three cuts in both the 2023 and 2024 seasons. Herb dry weights recorded were 59.1, 65.4, and 77.1 g/plant in the 1st, 2nd and 3rd cuts of 2023, and 60.7, 65.6, and 70.3 g/plant in the corresponding cuts of 2024 (Table 4). Leaf dry weights were 24.2, 30.3, and 36.6 g/plant in 2023 and 26.8, 31.8, and 36.4 g/plant in 2024 for the respective cuts (Table 5). Conversely, the lowest herb and leaf dry weights were observed with the EM-only treatment through all three cuts in both seasons.

3.1.3.3 Interaction between plant density and fertilizer treatments

The interaction between plant density and fertilizer treatments significantly affected herb and leaf dry weights (g)/plant/cut across all three cuts in both seasons. The highest herb and leaf dry weights were achieved with the lowest plant density (42 plants/10.8 m²) combined with 75% NPK + EM, yielding herb dry weights of 64.6, 70.8, and 77.1 g/plant in 2023 and 66.1, 71.1, and 75.9 g/plant in 2024 and leaf dry weights of 29.7, 35.9 and 42.1 g/plant in 2023 and 32.2, 37.2 and 42.0 g/plant in 2024 for the first, second, and third cuts, respectively. The combination of 42 plants/plot with 100% NPK also performed well, producing herb dry weights of 56.3, 62.5, and 68.8 g/plant in 2023 and 57.8, 62.8, and 67.4 g/plant in 2024 and leaf dry weights of 21.4, 27.6, and 33.7 g/plant in 2023 and 24.1, 29.0, and 33.2 g/plant in 2024 for the respective cuts. These results outperformed other treatment combinations, as shown in Tables (4 and 5).

Table (4): Impact of plant density, NPK and EM treatments and their interactions on herb dry weight (g)/plant/cut of sweet basil (*Ocimum basilicum* L.) during 2023 and 2024 seasons.

Treatments (B)	Plant densities per 10.8 m^2 (A)							
	2023 season				2024 season			
	90	60	42	Mean (B)	90	60	42	Mean (B)
	1st Cut							
100% NPK_{RD}	51.3	54.8	62.7	56.3	53.0	56.3	64.2	57.8
EM without NPK	46.3	47.7	55.7	49.9	47.4	49.3	57.2	51.3
75% NPK_{RD} + EM	55.3	57.3	64.6	59.1	57.1	58.8	66.1	60.7
50% NPK_{RD} + EM	49.1	51.8	61.2	54.1	50.6	53.3	62.7	55.5
25% NPK_{RD} + EM	47.5	50.3	57.8	51.9	49.1	52.2	59.5	53.6
Mean (A)	49.9	52.4	60.4		51.4	54.0	61.9	
LSD 0.05	A: 1.4 B: 2.9 AB: 4.9				A: 1.6 B: 2.8 AB: 4.9			
	2nd Cut							
100% NPK_{RD}	57.7	61.0	68.9	62.5	57.8	61.3	69.1	62.8
EM without NPK	52.1	54.0	61.9	56.0	52.3	54.2	62.1	56.2
75% NPK_{RD} + EM	61.8	63.5	70.8	65.4	61.9	63.8	71.1	65.6
50% NPK_{RD} + EM	55.3	58.0	67.4	60.2	55.6	58.2	67.6	60.5
25% NPK_{RD} + EM	53.8	56.9	64.2	58.3	54.1	57.1	64.5	58.5
Mean (A)	56.1	58.7	66.6		56.3	58.9	66.9	
LSD 0.05	A: 1.6 B: 2.8 AB: 4.9				A: 1.7 B: 2.7 AB: 4.8			
	3rd Cut							
100% NPK_{RD}	64.0	67.3	75.1	68.8	62.5	66.0	73.7	67.4
EM without NPK	58.4	60.2	68.1	62.2	57.1	59.0	66.7	60.9
75% NPK_{RD} + EM	68.1	69.7	77.1	71.6	66.7	68.4	75.9	70.3
50% NPK_{RD} + EM	61.5	64.2	73.6	66.4	60.4	63.0	72.4	65.3
25% NPK_{RD} + EM	60.0	63.1	70.4	64.5	58.7	61.9	69.1	63.2
Mean (A)	62.4	64.9	72.8		61.1	63.7	71.5	
LSD 0.05	A: 1.7 B: 2.9 AB: 5.0				A: 1.6 B: 2.8 AB: 4.9			

Table (5): Impact of plant density, NPK and EM treatments and their interactions on leaf dry weight (g)/plant/cut of sweet basil (*Ocimum basilicum* L.) during 2023 and 2024 seasons.

Treatments (B)	Plant densities per 10.8 m^2 (A)							
	2023 season				2024 season			
	90	60	42	Mean (B)	90	60	42	Mean (B)
	1st Cut							
100% NPK_{RD}	16.4	20.0	27.8	21.4	19.2	22.5	30.5	24.1
EM without NPK	11.2	14.9	20.8	15.7	13.8	15.5	23.3	17.5
75% NPK_{RD} + EM	20.5	22.5	29.7	24.2	23.3	24.9	32.2	26.8
50% NPK_{RD} + EM	14.3	17.0	26.4	19.2	16.8	19.4	28.8	21.7
25% NPK_{RD} + EM	12.7	16.2	24.9	17.9	15.3	18.4	25.9	19.8
Mean (A)	15.0	18.1	25.9		17.7	20.1	28.1	
LSD 0.05	A: 1.5 B: 2.3 AB: 4.0				A: 2.3 B: 2.2 AB: 4.0			
	2nd Cut							
100% NPK_{RD}	22.8	26.1	33.7	27.6	24.2	27.5	35.3	29.0
EM without NPK	17.1	19.1	26.7	21.0	18.6	20.3	28.3	22.4
75% NPK_{RD} + EM	26.7	28.4	35.9	30.3	28.2	30.0	37.2	31.8
50% NPK_{RD} + EM	20.4	23.1	32.4	25.3	21.5	24.3	33.2	26.4
25% NPK_{RD} + EM	18.9	21.9	28.1	23.0	20.1	22.8	29.8	24.3
Mean (A)	21.2	23.7	31.4		22.5	25.0	32.8	
LSD 0.05	A: 2.3 B: 2.4 AB: 4.1				A: 2.2 B: 2.6 AB: 4.6			
	3rd Cut							
100% NPK_{RD}	29.0	32.3	39.7	33.7	28.8	31.7	39.1	33.2
EM without NPK	23.6	25.2	33.1	27.3	23.0	25.1	32.5	26.9
75% NPK_{RD} + EM	33.1	34.7	42.1	36.6	32.7	34.5	42.0	36.4
50% NPK_{RD} + EM	26.5	29.2	38.6	31.4	26.5	29.2	38.0	31.2
25% NPK_{RD} + EM	25.0	28.1	34.7	29.3	24.9	27.8	35.1	29.3
Mean (A)	27.4	29.9	37.6		27.2	29.7	37.3	
LSD 0.05	A: 2.7 B: 2.5 AB: 4.3				A: 2.8 B: 2.2 AB: 3.9			

3.1.4 Total herb and leaf dry weights (g/plant/season and ton/feddan/season)

3.1.4.1 Impact of plant density

Data in Tables (6, 7, 8, and 9) reveal that plant density significantly impacted total herb and leaf dry weights (g)/plant/season and (ton)/feddan/season. The lowest plant density (42 plants/10.8 m² or 15555 plants/fed) produced the highest dry weights per plant, with herb dry weights of 199.85 and 200.34 g/plant/season and leaf dry weights of 94.94 and 95.25 g/plant/season in the 2023 and 2024 seasons, respectively, compared to higher densities (33333 and 22222 plants/fed) (Tables 5 and 6). In contrast, the highest density (90 plants/plot or 33333 plants/fed) resulted in the greatest yields per unit area, recording 5.61 and 5.63 ton/fed/season for herb dry weight and 2.12 and 2.25 ton/fed/season for leaf dry weight in 2023 and 2024, respectively, compared to lower densities (15555 and 22222 plants/feddan) (Tables 8 and 9).

3.1.4.2 Impact of fertilizer treatments

All five fertilizer treatments, combining NPK and effective microorganisms (EM), significantly increased total herb and leaf dry weights (g/plant/season and ton/fed/season) across the 2023 and 2024 seasons (Tables 6, 7, 8, and 9). The 50% NPK recommended dose (RD) + EM treatment yielded the highest values, recording herb dry weights of 196.04 and 196.54 g/plant/season and 4.57 and 4.58 ton/fed/season and leaf dry weights of 91.20 and 95.03 g/plant/season and 2.08 and 2.18 ton/feddan/season in the 2023 and 2024 seasons, respectively, surpassing all other treatments. In contrast, the EM-only treatment resulted in the lowest values for these parameters across all three cuts in both seasons.

Table (6): Impact of plant density, NPK and EM treatments and their interactions on total herb dry weight (g)/plant/season of sweet basil (*Ocimum basilicum* L.) during 2023 and 2024 seasons.

Treatments (B)	Plant densities per 10.8 m² (A)							
	2023 season				2024 season			
	90	60	42	Mean (B)	90	60	42	Mean (B)
100% NPK_{RD}	173.01	183.20	206.60	187.60	173.41	183.60	207.00	188.00
EM without NPK	156.80	161.87	185.60	168.09	156.80	162.53	186.00	168.44
75% NPK_{RD} + EM	185.17	190.50	212.47	196.04	185.67	190.93	213.03	196.54
50% NPK_{RD} + EM	165.97	174.10	202.17	180.74	166.57	174.60	202.60	181.26
25% NPK_{RD} + EM	161.30	170.27	192.43	174.67	161.90	171.13	193.07	175.37
Mean (A)	168.45	175.99	199.85		168.87	176.56	200.34	
LSD 0.05	A: 4.81 B: 8.60 AB: 14.90				A: 5.00 B: 8.51 AB: 14.82			

3.1.4.3 Interaction between plant density and fertilizer treatments

The interaction between plant density and fertilizer treatments (A×B) influenced total herb and leaf dry weights (g/plant/season and ton/feddan/season) in both seasons (Tables 6, 7, 8, and 9). The most effective combination for per-plant dry weights (g/plant/season) was the lowest density (42 plants/plot or 15555 plants/fed) paired with 75% NPK + EM (Tables 6 and 7). For yields per unit area (ton/feddan/season), the highest values were obtained with the highest density (90 plants/10.8 m² or 33,333 plants/feddan) combined with 75% NPK RD + EM (Tables 7 and 8).

Table (7): Impact of plant density, NPK and EM treatments and their interactions on total leaf dry weight g /plant/season of sweet basil (*Ocimum basilicum* L.) during 2023 and 2024 seasons.

Treatments (B)	Plant densities per 10.8 m^2 (A)							
	2023 season				2024 season			
	90	60	42	Mean (B)	90	60	42	Mean (B)
100% NPK$_{RD}$	68.24	78.47	101.30	82.67	72.24	81.73	104.93	86.30
EM without NPK	51.93	59.17	80.63	63.91	55.37	60.90	84.07	66.78
75% NPK$_{RD}$ + EM	80.30	85.57	107.73	91.20	84.23	89.40	111.47	95.03
50% NPK$_{RD}$ + EM	61.20	69.30	97.37	75.96	64.87	72.93	100.03	79.28
25% NPK$_{RD}$ + EM	56.57	66.13	87.67	70.12	60.33	69.00	90.73	73.36
Mean (A)	63.65	71.73	94.94		67.41	74.79	98.25	
LSD 0.05	A: 6.30 B: 7.01 AB: 12.10				A: 6.71 B: 6.82 AB: 11.82			

Table (8): Impact of plant density, NPK and EM treatments and their interactions on total herb dry weight ton/feddan/season of sweet basil (*Ocimum basilicum* L.) during 2023 and 2024 seasons.

Treatments (B)	Plant densities per 10.8 m^2 (A)							
	2023 season				2024 season			
	90	60	42	Mean (B)	90	60	42	Mean (B)
100% NPK$_{RD}$	5.77	4.07	3.21	4.35	5.78	4.08	3.22	4.36
EM without NPK	5.23	3.60	2.89	3.90	5.23	3.61	2.89	3.91
75% NPK$_{RD}$ + EM	6.17	4.23	3.30	4.57	6.19	4.24	3.31	4.58
50% NPK$_{RD}$ + EM	5.53	3.87	3.14	4.18	5.55	3.88	3.15	4.19
25% NPK$_{RD}$ + EM	5.38	3.78	2.99	4.05	5.40	3.80	3.00	4.07
Mean (A)	5.61	3.91	3.11		5.63	3.92	3.12	
LSD 0.05	A: 0.15 B: 0.18 AB: 0.32				A: 0.14 B: 0.17 AB: 0.31			

Table (9): Impact of plant density, NPK and EM treatments and their interactions on total leaf dry weight ton/feddan/season of sweet basil (*Ocimum basilicum* L.) during 2023 and 2024 seasons.

Treatments (B)	Plant densities per 10.8 m^2 (A)							
	2023 season				2024 season			
	90	60	42	Mean (B)	90	60	42	Mean (B)
100% NPK$_{RD}$	2.27	1.74	1.58	1.86	2.41	1.82	1.63	1.95
EM without NPK	1.73	1.31	1.25	1.43	1.85	1.35	1.31	1.50
75% NPK$_{RD}$ + EM	2.68	1.90	1.68	2.08	2.81	1.99	1.73	2.18
50% NPK$_{RD}$ + EM	2.04	1.54	1.51	1.70	2.16	1.62	1.56	1.78
25% NPK$_{RD}$ + EM	1.89	1.47	1.36	1.57	2.01	1.53	1.41	1.65
Mean (A)	2.12	1.59	1.48		2.25	1.66	1.53	
LSD 0.05	A: 0.21 B: 0.16 AB: 0.28				A: 0.20 B: 0.17 AB: 0.29			

3.2 Essential oil production

3.2.1 Essential oil percentage

3.2.1.1 Impact of plant density

Data in Table (10) reveal that plant density influenced essential oil percentage at a 5% significance level. A decrease in plant density was associated with a significant increase in essential oil percentage across all three cuts in both the 2023 and 2024 seasons. The lowest plant density (42 plants/10.8 m², equivalent to 15555 plants/feddan) yielded the highest essential oil percentages, recording 1.026, 1.115 and 1.173% in the first, second, and third cuts of 2023, and 1.065, 1.123 and 1.139% in the corresponding cuts of 2024. No significant differences were observed between the higher density levels (90 and 60 plants/plot, equivalent to 33333 and 22,222 plants/feddan) through all cuts in both seasons.

Table (10): Impact of plant density, NPK and EM treatments and their interactions on essential oil percentage/plant/cut of sweet basil (*Ocimum basilicum* L.) during 2023 and 2024 seasons.

Treatments (B)	Plant densities per 10.8 m^2 (A)							
	2023 season				2024 season			
	90	60	42	Mean (B)	90	60	42	Mean (B)
	1st Cut							
100% NPK_{RD}	1.017	1.053	1.058	1.042	0.997	1.030	1.090	1.039
EM without NPK	0.898	0.930	0.964	0.931	0.880	0.936	1.023	0.947
75% NPK_{RD} + EM	1.029	1.038	1.060	1.042	0.988	1.067	1.107	1.054
50% NPK_{RD} + EM	1.010	1.011	1.027	1.016	0.964	1.024	1.067	1.018
25% NPK_{RD} + EM	1.007	1.008	1.022	1.012	0.960	0.998	1.038	0.999
Mean (A)	0.992	1.008	1.026		0.958	1.011	1.065	
LSD 0.05	A: 0.044 B: 0.047 AB: 0.081				A: 0.100 B: 0.046 AB: 0.079			
	2nd Cut							
100% NPK_{RD}	1.047	1.080	1.140	1.089	1.020	1.080	1.163	1.088
EM without NPK	0.930	0.986	1.073	0.997	0.943	0.963	1.060	0.989
75% NPK_{RD} + EM	1.038	1.117	1.157	1.104	1.027	1.097	1.180	1.101
50% NPK_{RD} + EM	1.014	1.074	1.117	1.068	1.004	1.074	1.133	1.070
25% NPK_{RD} + EM	1.010	1.048	1.088	1.049	1.020	1.050	1.077	1.049
Mean (A)	1.008	1.061	1.115		1.003	1.053	1.123	
LSD 0.05	A: 0.100 B: 0.046 AB: 0.080				A: 0.055 B: 0.070 AB: 0.122			
	3rd Cut							
100% NPK_{RD}	1.070	1.130	1.213	1.138	1.071	1.104	1.164	1.113
EM without NPK	0.993	1.013	1.110	1.039	0.954	1.010	1.097	1.021
75% NPK_{RD} + EM	1.077	1.147	1.230	1.151	1.062	1.141	1.181	1.128
50% NPK_{RD} + EM	1.054	1.124	1.183	1.120	1.038	1.098	1.141	1.092
25% NPK_{RD} + EM	1.070	1.100	1.127	1.099	1.034	1.072	1.112	1.073
Mean (A)	1.053	1.103	1.173		1.032	1.085	1.139	
LSD 0.05	A: 0.056 B: 0.071 AB: 0.123				A: 0.099 B: 0.045 AB: 0.078			

3.2.1.2 Impact of fertilizer treatments

All fertilizer treatments significantly enhanced the essential oil percentage across all three cuts in both the 2023 and 2024 seasons. Among the five treatments, the combination of 75% NPK recommended dose (RD) + effective microorganisms (EM) yielded the highest essential oil percentages, recording 1.042, 1.104, and 1.151% in the first, second, and third cuts of 2023, respectively, and 1.054, 1.101, and 1.128% in the corresponding cuts of 2024. The 100% NPK treatment followed closely, with values of 1.042, 1.089, and 1.138% in 2023 and 1.039, 1.088, and 1.113% in 2024 for the respective cuts, outperforming the remaining treatments (Table 10). Conversely, the EM-only treatment resulted in the lowest essential oil percentages in both seasons through all three cuts.

3.2.1.3 Interaction between plant density and fertilizer treatments

The interaction between plant density and fertilizer treatments (A×B) significantly affected essential oil percentage across all three cuts in both seasons (Table 10). The highest essential oil percentages were achieved with the lowest plant density (42 plants/10.8 m²) combined with either 75% NPK + EM or 100% NPK, demonstrating the most effective treatment combinations for maximizing essential oil %.

3.2.2 Essential oil yield (ml/plant/cut)

Impact of plant density

Plant density significantly influenced essential oil yield (ml/plant/cut) through both the 2023 and 2024 seasons, as shown in Table (11). A reduction in plant density led to an increase in essential oil yield per plant per cut. No significant differences were observed between the density levels of 90 and 60 plants/10.8 m² (equivalent to 33333 and 22222 plants/feddan) in the third cut of the 2023 season. The lowest density (42 plants/plot or 15555 plants/feddan) consistently produced the highest essential oil yield ml per plant per cut in both seasons.

Table (11): Impact of plant density, NPK and EM treatments and their interactions on essential oil yield ml/plant/cut of sweet basil (*Ocimum basilicum* L.) during 2023 and 2024 seasons.

Treatments (B)	Plant densities per 10.8 m^2 (A)							
	2023 season				2024 season			
	90	60	42	Mean (B)	90	60	42	Mean (B)
	1st Cut							
100% NPK_{RD}	0.168	0.211	0.295	0.224	0.192	0.231	0.331	0.251
EM without NPK	0.101	0.138	0.200	0.146	0.121	0.143	0.236	0.166
75% NPK_{RD} + EM	0.210	0.232	0.314	0.252	0.230	0.264	0.356	0.284
50% NPK_{RD} + EM	0.144	0.172	0.271	0.196	0.162	0.200	0.309	0.224
25% NPK_{RD} + EM	0.128	0.163	0.254	0.182	0.147	0.184	0.268	0.200
Mean (A)	0.150	0.183	0.267		0.170	0.204	0.300	
LSD 0.05	A: 0.012 B: 0.023 AB: 0.041				A: 0.033 B: 0.027 AB:0.046			
	2nd Cut							
100% NPK_{RD}	0.239	0.281	0.384	0.301	0.247	0.298	0.410	0.318
EM without NPK	0.159	0.186	0.284	0.210	0.174	0.193	0.299	0.222
75% NPK_{RD} + EM	0.277	0.315	0.415	0.336	0.288	0.328	0.439	0.352
50% NPK_{RD} + EM	0.207	0.249	0.364	0.273	0.216	0.263	0.378	0.286
25% NPK_{RD} + EM	0.191	0.230	0.305	0.242	0.205	0.240	0.321	0.255
Mean (A)	0.215	0.252	0.350		0.226	0.264	0.369	
LSD 0.05	A: 0.033 B: 0.030 AB: 0.052				A: 0.038 B: 0.037 AB: 0.065			
	3rd Cut							
100% NPK_{RD}	0.310	0.367	0.481	0.386	0.309	0.349	0.455	0.371
EM without NPK	0.233	0.253	0.366	0.284	0.219	0.252	0.354	0.275
75% NPK_{RD} + EM	0.355	0.398	0.518	0.423	0.347	0.392	0.496	0.412
50% NPK_{RD} + EM	0.280	0.331	0.458	0.356	0.275	0.322	0.435	0.344
25% NPK_{RD} + EM	0.267	0.309	0.391	0.322	0.258	0.298	0.390	0.315
Mean (A)	0.289	0.331	0.443		0.282	0.323	0.426	
LSD 0.05	A: 0.047 B: 0.037 AB: 0.065				A: 0.039 B: 0.031 AB: 0.054			

3.2.2.1 Impact of fertilizer treatments

Data in Table (11) demonstrate that all five fertilizer treatments involving NPK and effective microorganisms (EM) significantly enhanced essential oil yield (ml/plant/cut) in both seasons. The combination of 75% NPK recommended dose + EM resulted in the highest essential oil yield ml per plant through all three cuts in both the 2023 and 2024 seasons, outperforming other treatments.

3.2.2.2 Interaction between plant density and fertilizer treatments

The interaction between plant density and fertilizer treatments (A×B) significantly increased essential oil yield (ml/plant/cut) in both seasons. The highest yields were achieved with the lowest plant density (42 plants/10.8 m²) combined with either 75% NPK RD + EM or 100% NPK, as detailed in Table (11).

3.2.3 Total essential oil yield (ml/plant/ season and l/feddan/season)

3.2.3.1 Impact of plant density

Data presented in Table (12) show that total essential oil yield (ml/plant/season) increased with decreasing plant density. The yields were 0.654, 0.767, and 1.060 ml/plant in the 2023 season and 0.678, 0.792, and 1.095 ml/plant in the 2024 season for densities of 90, 60, and 42 plants/plot (equivalent to 33333, 22222 and 15555 plants/fed), respectively. Conversely, essential oil yield per unit area (l/feddan/season) increased with higher plant density. The highest density (33333 plants/feddan) produced the greatest yields, recording 21.79 and 22.60 l/feddan/season in the 2023 and 2024 seasons, respectively, compared to 17.04 and 17.59 l/fed/season for 22222 plants/feddan and 16.49 and 17.04 l/feddan/season for 15555 plants/fed in the respective seasons (Table 12).

3.2.3.2 Impact of fertilizer treatments

Data in Tables (11 and 12) indicate that all fertilizer treatments including NPK and effective microorganisms significantly enhanced total essential oil yield (ml/plant/season and l/feddan/season) compared to EM without NPK. The 75% NPK recommended dose + EM treatment resulted in the highest yields, with 1.011 and 1.047 ml/plant/season and 22.83 and 23.61 l/feddan/season in the 2023 and 2024 seasons, respectively, outperforming other treatments across all three cuts.

3.2.3.3 Interaction between plant density and fertilizer treatments

The interaction between plant density and fertilizer treatments (A×B) significantly influenced total essential oil yield (ml/plant/season and l/fed/season) in both seasons. The highest yield per plant (ml/plant/season) was achieved with the lowest density (42 plants/10.8 m² or 15555 plants/feddan) combined with 75% NPK + EM, recording 1.246 and 1.291 ml/plant in the 2023 and 2024 seasons, respectively (Table 11). For yield (l/feddan/season), the highest values were obtained with the highest density (90 plants/plot or 33333 plants/fed) paired with 75% NPK + EM, yielding 28.08 and 28.85 l/feddan/season in the 2023 and 2024 seasons, respectively (Table 12).

Table (12): Impact of plant density, NPK and EM treatments and their interactions on total essential oil yield l/feddan/season of sweet basil (*Ocimum basilicum* L.) during 2023 and 2024 seasons.

Treatments (B)	Plant densities per 10.8 m^2 (A)							
	2023 season				2024 season			
	90	60	42	Mean (B)	90	60	42	Mean (B)
100% NPK_{RD}	23.92	19.08	18.03	20.34	24.93	19.52	18.61	21.02
EM without NPK	16.42	12.81	13.22	14.15	17.13	13.06	13.82	14.67
75% NPK_{RD} + EM	28.08	21.01	19.39	22.83	28.85	21.89	20.09	23.61
50% NPK_{RD} + EM	21.01	16.69	17.01	18.24	21.76	17.44	17.45	18.89
25% NPK_{RD} + EM	19.54	15.59	14.78	16.64	20.32	16.04	15.23	17.20
Mean (A)	21.79	17.04	16.49		22.60	17.59	17.04	
LSD 0.05	A: 2.34 B: 2.04 AB: 3.52				A: 2.72 B: 2.02 AB: 3.49			

3.3 Chemical Constituents

3.3.1 Nitrogen, phosphorus, and potassium percentages

3.3.1.1 Impact of plant density

Data presented in Table (13) indicate that sweet basil planted at the lowest density (42 plants/10.8 m² equivalent to 15555 plants/fed) exhibited the highest percentages of nitrogen (2.13 and 2.20), phosphorus (0.272 and 0.269), and potassium (2.31 and 2.27) in dry leaf samples for the 2023 and 2024 seasons, respectively, compared to higher densities (90 and 60 plants/10.8 m² equivalent to 33333 and 22222 plants/feddan). No significant differences in nitrogen percentage were observed between the 90 and 60 plants/plot density levels in either season.

3.3.1.2 Impact of fertilizer treatments

All fertilizer treatments (100% NPK, EM without NPK, 75% NPK + EM, 50% NPK + EM, and 25% NPK + EM) increased the percentages of nitrogen, phosphorus, and potassium in dry leaf samples across both seasons (Table 13). The treatments of 100% NPK and 75% NPK + EM resulted in the highest N, P, and K percentages compared to other treatments, with no significant differences between these two treatments.

3.3.1.3 Interaction between plant density and fertilizer treatments

The interaction between plant density and fertilizer treatments significantly influenced the percentages of nitrogen, phosphorus, and potassium in both seasons (Table 13). The most effective combination was the lowest plant density (42 plants/10.8 m²) paired with 100% NPK, followed closely by 75% NPK + EM, which yielded the highest N, P, and K percentages in both the 2023 and 2024 seasons.

Table (13): Impact of plant density, NPK and EM treatments and their interactions on dry leaf N, P and K percentages of sweet basil (*Ocimum basilicum* L.) during 2023 and 2024 seasons.

Treatments (B)	Plant densities per 10.8 m^2 (A)							
	2023 season				2024 season			
	90	60	42	Mean (B)	90	60	42	Mean (B)
	N%							
100% NPK_{RD}	2.20	2.24	2.32	2.25	2.16	2.20	2.29	2.22
EM without NPK	1.96	1.99	2.03	1.99	2.03	2.09	2.14	2.09
75% NPK_{RD} + EM	2.09	2.12	2.15	2.12	2.14	2.18	2.22	2.18
50% NPK_{RD} + EM	2.03	2.06	2.09	2.06	2.07	2.11	2.18	2.12
25% NPK_{RD} + EM	2.00	2.03	2.05	2.02	2.06	2.11	2.15	2.11
Mean (A)	2.06	2.09	2.13		2.09	2.14	2.20	
LSD 0.05	A: 0.06 B: 0.05 AB: 0.08				A: 0.10 B: 0.04 AB: 0.07			
	P%							
100% NPK_{RD}	0.271	0.276	0.286	0.278	0.265	0.278	0.283	0.275
EM without NPK	0.254	0.257	0.263	0.258	0.249	0.256	0.260	0.255
75% NPK_{RD} + EM	0.269	0.274	0.278	0.274	0.263	0.267	0.273	0.268
50% NPK_{RD} + EM	0.260	0.264	0.269	0.264	0.253	0.260	0.265	0.260
25% NPK_{RD} + EM	0.257	0.260	0.266	0.261	0.249	0.258	0.262	0.257
Mean (A)	0.262	0.266	0.272		0.256	0.264	0.269	
LSD 0.05	A: 0.004 B: 0.006 AB: 0.011				A: 0.005 B: 0.005 AB: 0.009			
	K%							
100% NPK_{RD}	2.28	2.33	2.37	2.33	2.20	2.27	2.33	2.22
EM without NPK	2.17	2.23	2.25	2.22	2.13	2.15	2.20	2.09
75% NPK_{RD} + EM	2.26	2.33	2.36	2.32	2.18	2.24	2.33	2.18
50% NPK_{RD} + EM	2.22	2.26	2.29	2.26	2.17	2.21	2.25	2.12
25% NPK_{RD} + EM	2.19	2.24	2.27	2.23	2.14	2.17	2.22	2.11
Mean (A)	2.22	2.28	2.31		2.16	2.21	2.27	
LSD 0.05	A: 0.03 B: 0.04 AB: 0.07				A: 0.04 B: 0.03 AB: 0.05			

4. Discussion

4.1 Impact of plant density on parameter traits

Plant density plays a crucial role as an agronomic factor in intercropping systems, significantly affecting crop performance and overall yield. According to Sattler and Bartelheimer (2018), poor management of planting density can lead to unfavorable outcomes in intercropping. For instance, low plant densities may restrict yield potential, whereas overly high densities can cause increased plant stress and heightened competition for essential resources such as light, water, and nutrients, ultimately resulting in reduced yields (Adeniyi and Omotunde, 2001). In line with this, Alemu *et al.* (2018) observed that higher basil population densities intensify competition for sunlight and nutrients, leading to longer stem lengths. Similarly, Pereira *et al.* (2015) noted that increased plant density promotes stem elongation because of stronger competition for light, which favors vertical growth over other developments. On the other hand, Fallah *et al.* (2018) found that wider spacing between plants encourages a higher number of branches, as there is more room for lateral expansion. However, Sadeghi *et al.* (2009) emphasized basil's sensitivity to plant density, pointing out that very low densities do not maximize fresh herb yield per unit area. At higher densities, individual plant weight often decreases due to limited growth and development from competition, which aligns with findings by Faridvand *et al*. (2021), who reported that reduced competition in basil allows better access to light, enhancing chlorophyll accumulation and aboveground biomass. Wider spacing improves individual plant growth by lessening rivalry for light, water, and nutrients, but this benefit for single plants does not fully compensate for the fewer plants per area, leading to lower total biomass. As a result, higher densities tend to increase dry matter yield, which positively influences essential oil yield per feddan. Comparable results were seen in studies on *Ocimum spp*. by Ram *et al.* (2002) and Arabasi and Bayran (2004), as well as on Melissa officinalis by Katar and Gurbuz (2008). Furthermore, the percentage of essential oil decreases as plant density rises, consistent with observations by El-Gendy *et al*. (2001) and Atghaei *et al*. (2015) for *Ocimum basilicum*. Plants under high light conditions exhibit greater essential oil content than those in low light, since light availability strongly affects essential oil biosynthesis (Gavrić *et al*., 2021). This suggests that denser populations can elevate total essential oil content in basil. Supporting evidence comes from Akbari *et al*. (2018), Alemu *et al*. (2018), and Lin *et al*. (2021), who indicated that plant population density impacts growth by modifying nutrient uptake and light exposure, thereby influencing photosynthesis and essential oil production. The drop in essential oil yield at lower densities is attributed to reduced herbal biomass. The study highlights plant density's importance in improving basil's chemical constituents (*Ocimum basilicum* L.), with lower densities linked to higher NPK percentages in dry leaves. These findings match those of El-Shaer (1986) for fennel, showing increases in NPK in dry herbs as density decreases.

4.2 Impact of NPK on parameter traits

Long-term use of chemical fertilizers like NPK can degrade soil, lower its fertility, and cause heavy metal accumulation in plant tissues, which harms the nutritional quality and safety of edible produce (Tamara *et al*., 2005). Nutrition is widely recognized to profoundly influence plant growth, yield, and fruit quality (Kassem and Marzouk, 2002), but the high cost of mineral fertilizers poses a major hurdle for farmers. Recent research also highlights health and environmental risks from these fertilizers, including soil depletion that necessitates higher chemical inputs, leading to substantial pollution over time. In sweet basil (*Ocimum basilicum* L.), NPK fertilizers notably affect growth parameters, essential oil content and chemical constituents, as evidenced in Tables 1-13 of the original study. Increasing NPK rates led to improvements in plant height, branch count, herb and leaf dry weights, essential oil content and leaf chemical constituents, peaking at 100% of the recommended dose. This boost is likely from NPK's stimulation of vegetative growth. Similar patterns were reported by Kamrozzman *et al.* (2016) in coriander. Ghatas and Mohamed (2018) also observed NPK's positive effects on growth, including higher total plant dry weight. The 100% recommended NPK dose significantly increased basil height, aligning with Alhasan *et al*. (2020) and Abbas *et al*. (2020) for sweet basil, Yousuf *et al*. (2014) and Kamrozzman *et al.* (2016) for coriander, and Abbas and Ali (2011) for roselle. Nitrogen, phosphorus, and potassium (NPK) are indispensable macronutrients that play pivotal roles in the physiological and biochemical processes underpinning plant growth, development, and secondary metabolite production, including essential oils in medicinal plants. The following sections provide an in-depth analysis of their functions, supported by seminal research, with a focus on their influence on vegetative growth and essential oil yield. Nitrogen is a fundamental nutrient critical for plant growth and development, serving as a structural and functional component of amino acids, enzymes, and energy transfer molecules such as chlorophyll, adenosine diphosphate (ADP), and adenosine triphosphate (ATP). According to Bidwell (1974), nitrogen is essential for the synthesis of proteins and nucleic acids, which are vital for cell division and the formation of new tissues. The availability of nitrogen directly correlates with plant growth rates, as it facilitates the proliferation of meristematic cells and supports the expansion of vegetative structures (Thompsond and Troch, 1975). Phosphorus is a vital element for plant cellular processes, particularly in cell division, the development of meristematic tissues, and carbohydrate metabolism. Lambers *et al*. (2000) highlight its involvement in numerous phosphorylation reactions, where it forms energy-rich phosphate bonds in molecules such as ATP and ADP, driving glycolysis, photosynthesis, and the metabolism of amino acids and lipids. Additionally, phosphorus contributes to biological oxidation processes and the structural integrity of membranes and nucleic acids. Devlin (1972) notes that a deficiency in phosphorus disrupts the conversion of sugars into starch and cellulose, impairing cell wall formation and energy storage, which can severely limit plant growth and reproductive development. Potassium plays a significant role in supporting plant growth and elongation, primarily through its function in osmoregulation, which maintains turgor pressure and facilitates cell expansion. Mengel and Kirkby (1987) suggest that potassium may interact synergistically with indole acetic acid (IAA), a key plant hormone, to promote growth. Furthermore, potassium enhances carbon dioxide (CO_2) assimilation during photosynthesis and aids in the efficient translocation of carbohydrates from source leaves to storage tissues and developing organs. This nutrient's activation of enzymes involved in metabolic pathways further supports biomass accumulation and overall plant vigor. The combined availability of nitrogen, phosphorus, and potassium (NPK) has a synergistic effect on vegetative growth and biomass production. Mohammed (2020) and Ahmed *et al*.

(2019) demonstrated that elevated NPK application rates correlate with maximum biomass yields across various crops, attributing this to the comprehensive nutritional support provided by these macronutrients. Abdelraouf *et al*. (2013) specifically observed optimal vegetative growth in black cumin with the application of mineral NPK fertilizers, underscoring their efficacy in enhancing shoot and root development. As outlined by Tiessen (2008) and Fageria (2009), nitrogen is integral to the synthesis of nucleic acids, amino acids, enzymes, proteins, chlorophyll, and cell wall components; phosphorus supports nucleic acid formation, membrane stability, and energy transfer; and potassium activates enzymatic reactions while maintaining cellular water balance. These functions collectively bolster plant structural and metabolic capacity. The availability of NPK not only enhances vegetative growth but also influences the synthesis and yield of essential oils in medicinal plants. Onofrei *et al.* (2018) established a direct relationship between these macronutrients and the production of secondary metabolites, including essential oils, which are often concentrated in sweet basil. A positive correlation exists between vegetative biomass and essential oil yield, as increased vegetation provides a larger substrate for oil synthesis. Pariari and Bhattacharya (2001) observed this trend in ginger, where higher NPK levels resulted in greater foliage and correspondingly higher essential oil content. Nitrogen promotes the synthesis of proteins and carbohydrates, serving as building blocks for oil-producing tissues; phosphorus facilitates the movement of amino acids for protein synthesis; and potassium maintains turgor pressure, enhancing metabolic efficiency (Patra *et al*., 2002, in Japanese mint). El-Nagar *et al*. (2015) further linked nutrient application rates to increased essential oil content in basil, potentially due to improved plant growth, higher oil gland density, or enhanced monoterpene production. These findings align with Ghatas and Mohamed (2018), who reported that elevated NPK-induced vegetative growth significantly boosts essential oil yields, reflecting a robust metabolic response to nutritional enrichment.

4.3 Impact of effective microorganisms (EM) on parameter traits

Effective microorganisms (EM) serve as an affordable, eco-friendly biofertilizer, providing substantial benefits to crops and soil. As a sustainable nutrient source, EM reduces reliance on inorganic fertilizers and supports eco-agriculture (Hedga *et al*., 1999; Hauwaka, 2000). EM promotes growth via nitrogen fixation, hormone production, and better nutrient access, while enhancing soil properties and minimizing environmental damage (Correa, 2002). Kengo and Hui-Lian (2000) reported that EM inoculation improves crop growth, yield, quality, and soil health in plant-soil systems. EM includes over 60 microbes, such as lactic acid bacteria (e.g., Lactobacillus plantarum, Lactobacillus casei, and

Streptococcus lactis), photosynthetic bacteria, yeasts, and algae, producing lactic acids (Formowitz *et al*., 2007). It enhances yield and quality in ornamental plants, increasing key chemical constituents (Javaid, 2006; Singh, 2007). For apple trees, EM led to longer/thicker shoots, larger leaves, and higher chlorophyll (Sahain *et al*., 2007). EM also boosts nutrient status, especially NPK, iron, manganese, and zinc (Khaliq *et al*., 2006). However, Abdou *et al*. (2011) on basil, Barbara *et al*. (2012) on basil, and Cezary (2015) on Chamomilla recutita found no significant benefits in some practices. EM speeds organic matter breakdown, improving element availability and protecting against pathogens for better development and yields (Joshi *et al*., 2019; Nayak *et al*., 2020). Borowiak *et al*. (2021) noted EM increases soil activity and photosynthesis, potentially cutting fertilizer needs for sustainability. Olle and Williams (2013) found 70% of EM studies positive for growth, yield, quality, and protection. EM suppresses pathogens, solubilizes minerals, conserves energy, balances ecology, and improves photosynthesis/nitrogen fixation (Hidalgo *et al*., 2022; Rastogi *et al*., 2020). Szewczuk *et al.* (2016) showed EM strains positively affect plant features, functions, and substrates. Yet, some studies report limited or negative effects: Bajwa (2005), Javaid (2006), and Okorski *et al.* (2008) saw minimal/adverse impacts; Priyadi *et al*. (2005) and van Vliet *et al*. (2006) found none; Mayer *et al*. (2010) suggested growth suppression from nitrogen competition; Javaid *et al.* (2008) noted no effect on rye; and Javaid (2006) observed pea yield drops. Nitrogen levels matched Markiewicz (2000) (0.78-2.8% N) and Jadczak *et al*. (2006) (2.44-3.07% N). Khaliq *et al*. (2006) and Sahain *et al*. (2007) confirmed EM's positive effect on nitrogen, magnesium, and zinc in apples, while Golcz and Bosiacki (2008) saw higher nitrogen in thyme with mycorrhizae. EM sometimes reduced phosphorus uptake, despite improvements noted by Khaliq *et al*. (2006) and Sahain *et al*. (2007). Basil phosphorus matched (Seidler-Łożykowska *et al*., 2006, 2009). Potassium varied with EM methods, with increases in apples (Sahain *et al.,* 2007) and cotton (Khaliq *et al*., 2006).

5. Conclusion

To improve sweet basil productivity, it is recommended to use a high plant density (33333 plants/feddan) to achieve maximum herb and leaf dry and essential oil yields per feddan, which is ideal for commercial production, or a low density (15555 plants/fed) to increase branches, herb and leaf dry weights/plant, oil percentage, and leaf nutrient content (NPK), which is suitable for high-quality oil production. Use a reduced dose of NPK (75%) with effective microorganisms (EM), administered several times during the season, to achieve peak growth, branch number, dry weight, and essential oil content. EM promotes soil health, reducing the use of mineral fertilizers. Future research should investigate the long-term effects of EM.

References

Abbas, M. K. and Ali, S. A. (2011), "Effect of foliar application of NPK on some growth characters of two cultivars of roselle (*Hibiscus sabdariffa* L.)", *American Journal of Plant Physiological*, Vol. 6 No. 4, pp. 220–227.

Abbas, M. S. (2014), "Assessment of density and cultivation type on growth and yield of two cultivars of basil (*Ocimum basilucum*, L.)", *International Journal of Agronomy and Agricultural Research*, Vol. 5 No. 1, pp. 74–79.

Abbas, S. S., Subaih, A. J. and Saleh, Y. A. (2020), "The effects of biological and chemical agents on the management of main pests in tomato plant", *Al-Qadisiyah Journal for Agriculture Sciences*, Vol. 10 No. 2, pp. 325–334.

Abdelraouf, E., El-Habbasha, F., Taha, H. and Refaie, M. (2013), "Effect of irrigation water requirements and fertigation levels on growth, yield and water use efficiency in wheat", *Middle-East Journal Science and Research*, Vol. 4, pp. 441–450.

Abdou, M. A. H., Abdalla, M. Y., Hegazy, A. A. and Marzok, Z. S. A. (2011), "Physiological studies on anise plant. 1-Effect of organic and bio-fertilizer on vegetative growth and chemical composition", *Journal of Horticultural Science & Ornamental Plants*, Vol. 3 No. 2, pp. 119–128.

Adeniyi, O. R. and Omotunde, C. T. (2001), "Effect of planting pattern on growth and yield of tomato-cowpea intercrops", *Journal of vegetable crop production*, Vol. 7 No. 2, pp. 75–81.

Ahmed, S., Elsayed, O., Mohamed, H., Eman, S. and Amira, O. (2019), "Influence of foliar fertilization on the growth and yield of chia (*Salvia hispanica*) plant", *Egyptian Pharmaceutical Journal*, Vol. 18, pp. 263–275

Akbari, G. A., Soltani, E., Binesh, S. and Amini, F. (2018), "Cold tolerance, productivity and phytochemical diversity in sweet basil (*Ocimum basilicum* L.) accessions", *Industrial Crops and Products*, Vol. 124, pp. 677–684.

Alemu, A., Garedew, W. and Gebre, A. (2018), "Essential oil yield and yield components of basil (*Ocimum basilicum* L.) as affected by genotype and intrarow spacing at Jimma, SW Ethiopia", *Acta Agrobotanica*, Vol. 71 No. 3, pp. 1–9.

Alhasan, A., Al-Ameri, D., Al-Baldawy, M., Abbas, M. and Hasan, H. (2020), "Influence of foliar application of NPK on growth, essential oil and seed yield of basil (*Ocimum basilicum* L. cv Dolly)", *Plant Archives*, Vol. 20, pp. 288–291.

Andrea, C., Lingua, G., Bardi, L., Masoeroand, G. and Berta, G. (2007), "Influence of *Arbuscular mycorrhizal* fungi on growth and essential oilcomposition in *Ocimum* *basilicum* var. Genovese", *Caryologia,* Vol. 60, pp. 106–110.

Arabaci, O. and Bayram, E. (2004), "The effect of nitrogen fertilization and different plant densities on some agronomic and technologic characteristic of basil (*Ocimum basilicum* L.)", *Journal of Agronomy*, Vol. 3 No. 4, pp. 255–262.

Atghaei, M. S., Rajabi, A. and Hemayaty, S. S. (2015), "Investigating the effect of bush density on the yield and leaf essence of green basil (*Ocimum basilicum*)", *International Journal of Research Studies in Agricultural Sciences*, Vol. 1 No. 1, pp. 11–17.

Bagali, A. N., Patil, H. B., Chimmad, V. P. Patil, P. L. and Patil, R. V. (2012), "Effect of inorganics and organics on growth and yield of onion (*Allium cepa* L.)", *Karnataka Journal of Agricultural Sciences,* Vol. 25 No. 1, pp. 112–115.

Bajwa, R. (2005), "Effects of arbuscular mycorrhizae (AM) and effective microorganisms (EM) on various plants under allelopathic stress", *Allelopathy Journal*, Vol. 16, pp. 261–271.

Barbara, F., Tomasz, K. and Justyna, K. (2012), "Impact of effective microorganisms on yields and nutrition of sweet basil (*Ocimum basilicum* L.) and microbiological properties of the substrate", *African Journal of Agricultural Research,* Vol. 7 No. 43, pp. 5756–5765.

Bekhradi, D. M., Kashi, A., Babalar, M. and Ilkhani, S. (2014), "Effect of plant density in some basil cultivars on yield and radiation use efficiency", *Journal of Biodiversity and Environmental Sciences*, Vol. 5 No. 1, pp. 91–96.

Bidwell, R. G. S. (1974), *Plant Physiology*, Macmillan Publishing Co. Inc., New York, USA, pp. 643.

Boligłowa, E. and Gleń, K. (2008), "Assessment of effective microorganisms activity (EM) in winter wheat protection against fungal diseases", *Ecological Chemistry and Engineering*, Vol. 15 No. 1-2, pp. 23–27.

Borowiak, K., Wolna-Maruwka, A., Niewiadomska, A., Budka, A., Schroeter-Zakrzew-ska, A. and Stasik, R. (2021), "The effects of various doses and types of effective microorganism applications on microbial and enzyme activity of medium and the photosynthetic activity of scarlet sage", *Agronomy*, Vol. 11 No. 3, pp. 603.

British Pharmacopoeia (1963), *Determination of volatile oil in drug*, Pharmaceutical Press, London, United Kingdom.

Cezary, A.K. (2015), "Yield and quality of chamomile (*Chamomilla recutita* L.) Rausch.) raw Material depending on selected foliar spray and plant spacing", *Acta Scientiarum Polonorum Hortorum Cultus*, Vol. 14 No. 1, pp. 143–156.

Chegini, N., Zadeh, S., Rad, A. and Bitarafan, Z. (2012), "Study the nitrogen rate effect on sweet basil phonological stages and physiological indices under different plant densities and patterns", *International Journal of Science Advanced Technology*, Vol. 2 No. 4, pp. 25–33.

Correa, M. (2002), *The impact of effective microorganisms (E.M.) in various farming system*, Proceedings of the 7th International Conference on Kyusei Natur Farming, Christchurch, New Zealand.

Dadvand, M. R., Naghdibadi, H. and Nasri, M. (2009), "Variation of essential oil and yield in *Ocimum* affected by density and nitrogen fertilizers", *Iranian Research Journal of Medicinal Plant*, Vol. 27, pp. 70–80.

Daly, M. J. and Stewart, D. P. C. (1999), "Influence of effective microorganisms (EM) on vegetable production and carbon mineralization - a preliminary investigation", *Journal of Sustainable Agriculture*, Vol. 14, pp. 15–25.

Devlin, R. M. (1972), *Plant Physiology*, 3rd Edition, Van Nostrand Company, New York, USA.

Dzida, K. (2010), "Biological value and essential oil content in sweet basil (*Ocimum basilicum* L.) depending on calcium fertilization and cultivar", *Acta Scientiarum Polonorum Hortorum Cultus*, Vol. 9 No. 4, pp. 153–161.

Eissa, E. M. (2002), "Use of biostimulants in activation of soil microflora for yield and fruit quality improvements of "Canino" apricot", *Journal of Agricultural Research, Tanta University*, Vol. 28, pp. 354–364.

Ekren. S. Ç., Sonmeza, O. E., Kurttas, Y. S., Bayrama, E. and Gurgulu, H. (2012), "The effect of different irrigation water levels on yield and quality characteristics of purple basil (*Ocimum basilicum* L.)", *Agricultural Water Management*, Vol. 109, pp. 155–161.

El-Gendy, S. A., Hosni, A. M., Ahmed, S. S. and Sabri, R. M. (2001), "Sweet basil (*Ocimum basilicum,* L.) productivity under different organic fertlization and inter- plant spacing levels in newly reclaimed land in Egypt", *Annals of Agricultural Science*, Vol. 46 No. 1, pp. 319–338.

El-Nagar, H., Hassan, A., Shaban, H. and Mohamed, E. (2015), "Effect of organic and biofertilizers on growth, oil yield and chemical composition of the essential oil of *Ocimum basillicum* L. plants", *Alexandria Journal of Agricultural Research*, Vol. 60, pp. 1–16.

El-Shaer, S. T. (1986), *Effect of plant spacing and growth regulators on growth, seed yield and volatile oil of fennel plant*, M.Sc. Thesis, Faculty of Agriculture, Zagazig University, Egypt.

Esetlili, B. Ç., Öztürk, B., Çobanoğlu, Ö. and Anaç, D. (2016), "Sweet basil

(*Ocimum basilicum* L.) and potassium fertilization", *Journal of Plant Nutrition*, Vol. 39 No. 1, pp. 35–44.

Fageria, K. (2009), *The use of nutrients in crop plants*, CRC Press, USA.

Fallah, S., Rostaei, M., Lorigooini, Z. and Abbasi, S. A. (2018), "Chemical compositions of essential oil and antioxidant activity of dragonhead (*Dracocephalum moldavica*) in sole crop and dragonhead- soybean (*Glycine max*) intercropping system under organic manure and chemical fertilizers", *Industrial Crops and Products*, Vol. 115, pp. 158–165.

Faridvand, S., Rezaei-Chiyaneh, E., Battaglia, M. L., Gitari, H. I., Raza, M. A. and Siddique, K. H. (2021), "Application of bio and chemical fertilizers improves yield, and essential oil quantity and quality of Moldavian balm (*Dracocephalum moldavica* L.) intercropped with mung bean (*Vigna radiata* L.)", *Food and Energy Security*, Vol. 11 No. 2, Article No. e319.

Formowitz, B., Elango, F., Okumoto, S., Muller, T. and Buerkert, A. (2007), "The role of effective microorganisms in the composting of banana (*Musa* ssp.) residues", *Journal of Plant Nutrition and Soil Science*, Vol. 170, pp. 649–656.

Gavrić, T., Jurković, J., Gadžo, D., Čengić, L., Sijahović, E. and Bašić, F. (2021)," Fertilizer effect on some basil bioactive compounds and yield", *Ciência e Agrotecnologia*, Vol. 45, Article No. e003121.

Ghatas, A. and Mohamed, F. (2018), "Influence of mineral, micro-nutrients and Lithovit in growth, oil productivity and volatile oil constituents of *Cymopogen citruts* L. plants", *Middle East Journal of Agriculture*, Vol. 7 No. 1, pp. 162–174.

Golcz, A. and Bosiacki, M. (2008), "Effect of nitrogen fertilization doses and mycorrhization on the yield and essential oil content in thyme (*Thymus vulgaris* L.)", *Journal of Research and Applications in Agricultural Engineering*, Vol. 53 No. 3, pp. 72–74.

Górski, R. and Kleiber, T. (2010), "Effect of effective microorganisms (EM) on nutrient contents in substrate and development and yielding of rose (*Rosa x hybrida*) and gerbera (*Gerbera jamesonii*)", *Ecological Chemistry and Engineering S,* Vol. 17 No. 4, pp. 505–513.

Hedga, D. M., Dwivedi, B. S. and Sudhakara, B. S. S. (1999), "Biofertilizers for cereal production in India – A review", *Indian Journal of Agricultural Sciences*, Vol. 69 No. 2, pp. 73–83.

Hidalgo, D., Corona, F. and Martín-Marroquín, J. M. (2022), "Manure biostabilization by effective microorganisms as a way to improve its agronomic value", *Biomass Conversion and Biorefinery,* Vol. 12

No. 10, pp. 4649–4664.

Higa, T. (2003), *EM Technology application in agriculture and environment protection*, In Proceedings of the 38 International Microbiological Symposium Effective Microorganisms (EM) in Sustainable Agriculture and Environmental Protection, SGGW, Rogów, Poland, pp. 17–18.

Higa, T. (2004), *Eine Revolution zur Rettung der Erde: mit effektiven Mikroorganismen (EM) die Probleme unserer Welt lösen*, OLV, Organischer Landbau-Verlag, Kevelaer, Germany.

Horneck, D. A. and Hanson, D. (1998), "Determination of potassium and sodium by flame Emission spectrophotometry", In *Handbook of reference methods for plant analysis*, CRC Press, USA, pp. 153–155.

Horneck, D. A. and Miller, R. O. (1998), "Determination of total nitrogen in plant tissue", In *Handbook of reference methods for plant analysis*, CRC Press, USA, pp. 75–83.

Iwaishi, S. (2000), "Effect of organic fertilizer and effective microorganisms on growth, yield and quality of paddy-rice varieties", *Journal of Crop Production*, Vol. 3 No. 1, pp. 269–273.

Jackson, M. L. (1973), *Soil Chemical Analysis Englewood Cliffs*, Pren-tice Hall Inc., New York, USA.

Jadczak, D., Błaszczuk, A., Rekowska, E. (2006), "Effect of covering on the content of macroelements in field of basil (*Ocimum basilicum* L.) cultivated for bunch harvest", *Elementology*, Vol. 11 No. 2, pp. 135-141.

Janas, R. (2009), "The possibilities of using effective microorganisms in organic crop production systems", *Problemy Inzynierii Rolniczej*, Vol. 17 No. 3, pp. 111–119.

Javaid, A. (2006), "Foliar application of effective microorganisms on pea as an alternative fertilizer", *Agronomy for Sustainable Development*, Vol. 26 No. 4, pp. 257–262.

Javaid, A., Bajwa, R. and Anjum, T. (2008), "Effect of heat-sterilization and EM (effective microorganisms) application on wheat (*Triticum aestivum* L.) grown in organic-amended sandy loam soil", *Cereal Research Communications*, Vol. 36 No. 3, pp. 489–499.

Joshi, H., Somduttand, C. P. and Mundra, S. L. (2019), "Role of effective microorganisms (EM) in sustainable agriculture", *International Journal of Current Microbiology and Applied Sciences*, Vol. 8 No. 3, pp. 172–181.

Kamrozzman, M., Ahmed, S. and Ouddus, R. (2016), "Effect of fertilizer on coriander seed production", *Bangladesh Journal of Agricultural Research*, Vol. 41 No. 2, pp. 345–352.

Kassem, H. A. and Marzouk, H. A. (2002), "Effect of organic and/or mineral nitrogen fertilization on the nutritional status, yield, and fruit quality of flame seedless grapevines grown in calcareous soils", *Journal of Advanced Agriculture Research,* Vol. 7 No. 1, pp. 118–126.

Katar, D. and Gurbuz, B. (2008), "The effect of different plant densities and nitrogen doses on drug leaf yield and some features of lemon balm (*Melissa officinalis*, L.)", *Tarim Bilimleri Dergisi*, Vol. 14 No. 1, pp. 78–81.

Kengo, Y. and Hui-lian, X. (2000), "Properties and applications of an organic fertilizer inoculated with effective microorganisms", *Journal of Crop Production*, Vol. 3 No. 1, pp. 255–268.

Khafi, M. (2003), *Basil-Production and Processing*, Ferdowsi University, Mashhad Publication, Mashhad, Iran, pp. 195.

Khaliq, A., Abbasi, M. K. and Hussain, T. (2006), "Effects of integrated use of organic and inorganic nutrient sources with effective microorganisms (EM) on seed cotton yield in Pakistan", *Bioresource Technology*, Vol. 97 No. 8, pp. 967–972.

Klama, J. and Kleiber, T. (2010), "The influence of manganese fertigation on the number of substrate microflora and yield of tomato in rock wool cultivation", *Nauka Przyroda Technologie*, Vol. 4 No. 6, Article No. 82.

Lambers, H., Chapin, F. S. and pons, T. L. (2000), *Plant physiology Ecology*, Springer-Verlag, New York, USA.

Lin, K., Huang, M. and Hsu, M. (2021), "Morphological and physiological response in green and purple basil plants (*Ocimum basilicum*) under different proportions of red, green and blue LED lightings", *Scientia Horticulturae*, Vol. 275, Article No. 109677.

Markiewicz, B. (2000), *The influence of mineral fertilization on the yielding and oil content is sweet basil (Ocimum basilicum L.)*, M.Sc. Thesis, Poznań University of Life Sciences, Poland (in Polish).

Mayer, J., Scheid, S., Widmera, F., Fließbach, A. and Oberholzer, H. R. (2010), "How effective are Effective microorganisms® (EM)? Results from a field study in temperate climate", *Applied Soil Ecology*, Vol. 46 No. 2, pp. 230–239.

Mead, R. N., Carrow, R. N. and Harted, A. M. (1993), *Statistical Methods in Agricultural and Experimental Biology*, 2nd Ed., Chapman, London, pp. 10–44.

Mengel, K. and Kirkby, A. (1987), *Principles of Plant Nutrition*, 4th Ed., International Potash Institute, Bern, Switzerland.

Mohammed, M. A. (2020), "Structural, optical, electrical and gas sensor properties of ZrO_2 thin films prepared by Sol-Gel technique", *Neuroquantology*, Vol. 18 No. 3, pp. 22–27.

Mostafa, H. H. A., Li, B., Zhu, X. and Son, C. (2021), "Nitrogen assimilation under osmotic stress in maize (*Zea mays* L.) seedlings", *Plant Growth Regulation*, Vol. 94 No. 1, pp. 87–99.

Muthaura, C., Musyimi, D., Ogur, J. and Otello, S. (2010), "Effective Microorganisms and their influence on growth and yield of pigweed (*Amaranthus dubians*)", *ARPN Journal of Agricultural and Biological Science*, Vol. 5 No. 1, pp. 17–22.

Naguib, N. Y. M. (2011), "Organic vs chemical fertilization of medicinal plants: a concise review of researches", *Advances in Environmental Biology*, Vol. 5 No. 2, pp. 394–400.

Nayak, N., Sar, K., Sahoo, B. K. and Mahapatra, P. (2020), "Beneficial effect of effective microorganism on crop and soil-a review", *Journal of Pharmacognosy and Phyto-Chemistry*, Vol. 9 No. 4, pp. 3070–3074.

Okorski, A., Olszewski, J., Pszczokowska, A. and Kulik, T. (2008), "Effect of fungal infection and the application of the biological agent EM1 on the rate of photosynthesis and transpiration in pea (*Pisum sativum* L.) leaves", *Polish Journal of Natural Sciences*, Vol. 23 No. 1, pp. 35–47.

Olle, C. and Williams, I. H. (2013), "Effective microorganisms and their influence on vegetable production – A review", *Journal Horticultural Science Biotechnology*, Vol. 88 No. 4, pp. 380–386.

Onofrei, V., Amina, B., Magdalena, J., Sofia L., Walid, O., Marian, B., Andrei, L., Gabriel, C. T. and Teodor, R. (2018)," Ecological foliar fertilization eects on essential oil composition of sweet basil (*Ocimum basilicum* L.) cultivated in a field system", *Scientia Horticultureae,* Vol. 239, pp. 104–113.

Pariari A. and Bhattacharya, A. (2001), "Yield and quality of ginger as influenced by different doses of N and P", *Journal of International for Academician*, Vol. 5 No. 1, pp. 123–126.

Patra, D., Anwar, M., Chand, S., Kiran, U., Rajoput, K. and Kumar, S. (2002), "Neem and *Mentha spicata* oil as nitrification inhibitor for optimum yield of Japanese mint (*Mentha arvensis*)", *Communication of Soil Science and Plant Analysis*, Vol. 33, pp. 451–460.

Pereira, A. L. C., Taques, T. C., Valim, J. O. S., Madureira, A. P. and Campos, W. G. (2015), "The management of bee communities by intercropping with flowering basil (*Ocimum basilicum*) enhances pollination and yield of bell pepper (*Capsicum annuum*)", *Journal of Insect Conservation*, Vol. 19 No. 3, pp. 479–486.

Priyadi, K., Abdul, H., Siagian, T.H., Nisa, C., Azizah, A., Raihani, N. and Inubushi, K. (2005), "Effect of soil type, applications of chicken manure and effective microorganisms on corn yield and microbial properties of acidic wetland soils in Indonesia", *Soil Science & Plant Nutrition*, Vol. 51 No. 5, pp. 689–691.

Ram, M., Ram, D., Nagvi, A. A. and Kumar, S. (2002), "Effect of plant density and harvesting time on the yield and the quality of essential oil on *Ocimum* spp.", *Journal of Medicinal and Aromatic Plant Science*, Vol. 24 No. 2, pp. 393–396.

Rastogi, M., Nandal, M., and Khosla, B. (2020), "Microbes as vital additives for solid waste composting", *Heliyon*, Vol. 6 No. 2, pp. 1–11.

Sadeghi, S., Rahnavard, A. and Ashrafi, Z. Y. (2009), "The effect of plant density and sowing date on yield of basil (*Ocimum basilicum* L.) in Iran", *Journal of Agricultural Technology*, Vol. 5 No. 2, pp. 413–422.

Sahain, M. F. M., Abd El Motty, E. Z., El-Shiekh, M. H. and Hagagg, L. F. (2007), "Effect of some biostimulant on growth and fruiting of an apple trees in newly reclaimed areas", *Research Journal of Agriculture and Biological Sciences*, Vol. 3 No. 5, pp. 422–429.

Sandell, R. (1950), *Colorimetric determination of traces of metal*, 2nd Ed., Interscience Publishers Inc., New York, USA.

Sattler, J. and Bartelheimer, M. (2018), "Root responses to legume plants integrate information on nitrogen availability and neighbour identity", *Basic and Applied Ecology*, Vol. 27 pp. 51–60.

Seidler-Łożykowska, K., Kozik, E., Golcz, A. and Mieloszyk, E. (2006), "Macroelements and essential oil content in the raw material of the selected medicinal plant species from organic cultivation", *Journal of Research and Applications in Agricultural Engineering*, Vol. 51 No. 2, pp. 161–163.

Seidler-Łożykowska, K., Mordalski, R., Kucharski, W., Golcz, A., Kozik, E. and Wójcik, J. (2009), "Economic and qualitative value of the raw material of chosen species of medicinal plants from organic farming. Part II. Yield and quality of sweet basil herb (*Ocimum basilicum* L.)", *Acta Scientiarum Polonorum Agricultura*, Vol. 8 No. 3, pp. 29–35.

Shah, H. S., Farrukh S. M. and Shahid, M. (2001), "Effect of different fertilizers and effective microorganisms on growth, yield and quality of maize", *International Journal of Agriculture & Biology*, Vol. 3 No. 4, pp. 378–379.

Sharafzadeh, S. and Alizadeh, O. (2011), "Nutrient supply and fertilization of basil", *Advances in Environmental Biology*, Vol. 5 No. 5, pp. 956–960.

Singh, A. (2007), "Effective Microorganisms", *The Canadian Organic Grower*, Vol. 2, pp. 35–36.

Statistix (2009), *Statistix 9: Analytical Software Tallahassee*, FL., USA.

Szewczuk, C., Sugier, D., Baran, S., Bielińska, E. J. and Gruszczyk, M. (2016), "The impact of fertilising agents and different doses of fertilizers on selected soil chemical properties as well as the yield and quality traits of potato tubers", *Agronomy Science*, Vol. 71, No. 2, pp. 65–79.

Tamara, V. R., Nadezhda, G. K. and Natalya, A. M. (2005), "Influence of soil application of biological and mineral fertilizers on the growth, yield, and fruit biochemical components of 'Charavnitsa' apple, and on some agrochemical soil characteristics", *Acta Scientiarum Polonorum, Hortorum Cultus*, Vol. 4, pp. 59–67.

Telci, I., Bayram, E., Yilmaz, G. and Avci, B. (2006), "Variability in essential oil composition of Turkish basils (*Ocimum basilicum* L.)", *Biochemical Systematic Ecology*, Vol. 34, pp. 489–497.

Thompsond, L. M. and Troch, F. R. (1975), *Soils and Soil Fertility*, TATA Mc- Graw- Hill pub. Co. Ltd., New Delhi, India.

Tiessen, H. (2008), "Phosphorus in the global environment", In: White PJ, Hammond JP, edition, *The ecophysiology of plant-phosphorus interactions*, Springer USA, pp. 1–8.

USDA (2008), *Germplasm Resources Information Network (GRIN)*, National Germplasm Resources Laboratory, U.S. Department of Agriculture, Agricultural Research Service, USA.

Van Vliet, P. C. J., Bloem, J. and de Goede, R. G. M. (2006), "Microbial diversity, nitrogen loss and grass production after addition of effective microorganisms (R) (EM) to slurry manure", *Applied Soil Ecology*, Vol. 32 No. 2, pp. 188–198.

Wielgosz, E. and Szember, A. (2006), "The occurrence of natural soil microbial communities in rhizosphere of plants used in the management of domestic areas", *Agronomy Science*, Vol. 61, pp. 75–92.

Wielgosz, E., Dziamba, S. Z. and Dziamba, J. (2010), "Effect of application of EM spraying on the populations and activity of soil microorganisms occurring in the root zone of spring barley", *Polish Journal of Soil Science*, Vol. 43 No. 1, pp. 65–72.

World Health Organization (2008), *Traditional medicine* (Fact sheet No. 134), World Health Organization, Geneva, Switzerland.

Yousuf, N., Brahma, S. and Kamal, M. (2014), "Effect of nitrogen, phosphorus, potassium and sulpher on the growth and seed yield of coriander (*Coriandrum sativum* L.)", *Bangladesh Journal of Agricultural Research*, Vol. 39 No. 2, pp. 303–309.