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Potentiality of Organic and biological fertilizers effects on fennels growth, productivity and chemical constituents

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Abstract

To evaluate the effects of different organic and biological fertilizers on seed yield (Y/fed) and quantity of fennel essential oil (EO), an experiment was conducted in a completely randomized block design with three replications. The experimental treatments included two organic (compost and filter mud in 5 and 10 ton/fed each), NPK and two biological (seaweed and/or miccorhiza) fertilizers along with their interactions control (non-fertilized). There were significant differences between treatments in terms of vegetative growth traits, yield attributes and seed essential oil percentage. The combination of 10 ton FM with mixed bio-treatment of SW and MyC applications exhibited the highest significant effects on most vegetative growth traits and yield traits with increment percentage by 361% (Y/fed), 135% (Umbels number), 109.05% (number of leaves), 48.15% (EO) 41.18% (number of branches), 26.17% (plant height) and 2.49% (Carbohydrates) in descending order comparing with the general control (without Organic or Bio. application). However, the combinations of 5ton FM with mixed Bio treatment and with seaweed treatments application exhibited the highest significant effect on Essential oil content and Carbohydrates content with increment percentage by 69.9% and 10.33%, respectively comparing with the general control (without Org. or Bio. application).

Keywords: Fennel, organic, biological fertilizers, NPK, growth, productivity.

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1. Introduction

Fennel (*Foeniculum vulgare* Miller) is a widely kitchen herb used around the world and is classified as a medicinal and aromatic plant [1]. Numerous arid and semi-arid regions, including Egypt, especially the Fayoum governorate, are home to this Apiaceae family member [2,3]. Fennel can be consumed every day in a variety of ways, including raw in salads and snacks, stewed, cooked, grilled, baked, and even used to make herbal teas or spirits. The edible components of fennel contain compounds that have been found to have hepatic, antioxidant, and antibacterial qualities [4]. Vitamins A, B, and C, as well as potassium (K) and calcium, are abundant in the stems and leaves of fennel plants and are essential for several metabolic functions [1]. Furthermore, a number of studies have reported that the essential oil of fennel seeds (FSEO) exhibits biological activities, including hepatoprotective, antioxidant, antibacterial, antifungal, anti-diabetic, anti-neurological, and anticancer properties [5,6,7,8,9,10]. Long-term soil fertility, the soil environment, and its constituents are seriously threatened by the indiscriminate use of chemical (synthetic) fertilizers to improve productivity. However, promoting soil health and plant growth is greatly aided by the soil microbial community. The use of synthetic fertilizers, particularly N and P fertilizers, has a significant impact on the development of plants, but it also drastically alters the microbial community's composition toward a dangerously low level. Sustainable farming methods can preserve soil fertility and productivity while halting the loss of natural resources. One extremely promising strategy to lower emissions related to process chemical companies is to use minerals that contain fertilizer nutrients in their natural state.

One of the newest environmentally friendly technologies that will be employed in sustainable agriculture is biofertilizers. Because biofertilizers have a higher nutritional content, they increase soil fertility and plant productivity. Many different species can be used to make biofertilizers. Among them are microorganisms such as the microfungus Glomus spp. Biofertilizers can also be made from the remains of macroorganisms like plants, fungus, or algae. The fact that microorganisms and the remains of macroorganisms are not only biodegradable but also capable of safely increasing soil fertility without accumulating toxins lends credence to the ideals of sustainable development. By doing this, the environment and its ecosystems are kept intact. Extracts from seaweed improve the biological properties of the soil and increase productivity in the face of biotic and abiotic stress [11]. Furthermore, from the standpoints of affordability, energy efficiency, and environmental friendliness, the concept of employing mycorrhizal fungus as a biofertilizer is a promising one [12,13,14]. An enormous, practical, and underutilized resource for managing soil ecosystems is mycorrhiza. The majority of this varied group of fungus are found on plant roots [12,13,14,15]. Depleted agricultural soils may be remedied, restored, and sustained by combining organic matter with nutrient-bearing minerals and associated biological weathering agents.

All of the nutrients needed by medicinal and aromatic plants (MAPs) can be found in organic fertilizers. In addition to being healthy for the environment and human health, organic fertilizers, such as composting and recycling organic waste, such as food scraps, plant debris, and animal byproducts, also improve soil structure [16]. Therefore, this study aimed to investigate how fennel yield and morphological characteristics are affected when vegetable compost or filter mud (cane sugar industry waste) is used as an organic fertilizer for plants. Additionally, the impact on the previously mentioned parameters of applying a combination of seaweed and/or mycorrhizae, with the studied organic materials compost.

2. Materials and methods

2.1. Experimental site and soil properties

The study was carried out during the two successive seasons of 2021/22 and 2022/23 at the Experimental Farm of the Botany Department, Faculty of Science, South Valley University (having a Latitude: 26° 26' 52.44" North and Longitude: 33° 9' 7.704" East), Qena Governorate, Egypt, to study the response of fennel (*Foeniculum vulgare* Mill.) plants for organic and biofertilizers application.

2.2. Plant Material

The fennel seeds of cultivar “Florence” were obtained from Horticulture Research Institute, Agricultural Research Center (ARC), Giza, Egypt. The seeds were sown in nursery beds on November 15th in both seasons. Seedlings were thinned to two plants per hill and irrigated 21 days after sowing

2.3. Soil and water Properties

The experiment was conducted in Sandy loam soil using drip irrigation system. Prior to any practices, a composite soil sample was taken from the soil surface (0-30 cm) of the experimental site, air- dried, sieved by 2 mm sieve and analyzed. The chemical and physical properties of soil were determined according to Cottenie *et al.* (1982) as shown in Table 1.

Table 1: Physical and chemical properties of the soil used in this experiment

Texture	pH (1:2.5)	EC (ds/ m)	Calcium Carbonate (%)
Sandy loam	8.19	0.75	9.98
Organic Matter (%)	Total N (%)	Available P (mg/ kg)	Available K (mg/ kg)
0.74	0.015	4.41	114

2.4. The Experimental Layout

The experimental plot was three rows, 3 m in length with 60 cm between rows and a distance of 30 cm between plants in the row. The experiment was carried out with three replicates in a randomized split plot design where type of organic fertilizer treatments was the main plot and the type of biofertilizer was the subplot, whereas; one ridge was left without planting as a guard ridge between plots to avoid the interference of various treatments. The experiment included 24 treatments (6 Organic fertilizers × 4 Biofertilizer treatments) as shown in Table 2. The organic fertilizers (main plot) included Org.1 (5 ton/fed. compost), Org.2 (10 ton/fed. compost), Org.3 (5 ton/fed filter mud), Org.4 (10 ton/fed filter mud), NPK (50% recommended dose of mineral fertilization) as well as untreated control (C) without any fertilization. While the four biofertilizer treatments (sub-plot) included Bio.1 (5 ml/plant of seaweed extract), Bio.2 (5 g/plant of mycorrhizae), Bio.3 (Mixed Bio.1+Bio.2) as well as untreated control (W, irrigated with water only without using any fertilizers). Compost was manufactured in the Botany Department farm, Faculty of Science, South

Valley University, from fennel plant waste, whereas, filter mud was obtained from the sugar factory of Nag Hammadi, Qena Government. Two weeks before planting date, while preparing the soil, compost or filter mud were added in the two experimental seasons whereas biofertilizers, i.e., seaweed extract (SW) and mycorrhizae (MyC) were applied to the soil directly beside the plants after one month of sowing and repeated three times at 15-day intervals.

The mineral sources of N, P, and K fertilizers were 150 kg/fed ammonium sulphate (20.6% N), 100 kg/fed calcium superphosphate (15.5% P2O5), and 50 kg/fed potassium sulphate (48% K2O), respectively, as recommended dose (RD). NPK was applied at 50% RD level. The fertilizers application for N and K were made three times after planting, 15 days interval, while calcium super phosphate was added as one dose during the soil preparation. Intercultural operations were done as and whenever required.

Table 2: Organic fertilization and Bio-fertilizer treatments used in this study

Main-plot	Subplot			
	C (W)	Bio.1 (SW)	Bio.2 (MyC)	Bio.3 (Mix)
R1				
Control (C)	C x W (T1)	C x SW (T2)	C x MyCv (T3)	C x Mix (T4)
Org.1	Org.1 × W (T5)	Org.1 × SW (T6)	Org.1 × MyC (T7)	Org.1 × Mix (T8)
Org.2	Org.2 × W (T9)	Org.2 × SW (710)	Org.2 MYC (T11)	Org.2 × Mix (T12)
Org.3	Org.3 × W (T13)	Org.3 × SW (T14)	Org.3 × MyC (T15)	Org.3 × Mix (T16)
Org. 4	Org.4 x W (T17)	Org.4 × SW (T18)	Org.4 × MyC (T19)	Org.4 × Mix (T20)
NPK50	NPK X W (T21)	NPK X SW (T22)	NPK X MyC (T23)	NPK x Mix (T24)
R2				
Control (C)	C x W (T1)	CX SW (T2)	C MYC (T3)	C x Mix (T4)
Org.1	Org.1 x W (T5)	Org. 1 × SW (T6)	Org. 1 × MyC (T7)	Org.1 × Mix (T8)
Org.2	Org.2 × W (T9)	Org.2 x SW (T10)	Org.2 × MYC (T11)	Org.2 × Mix (T12)
Org.3	Org.3 × W (T13)	Org.3 × SW (T14)	Org.3 × MyC (T15)	Org.3 × Mix (T16)
Org. 4	Org.4 × W (T17)	Org.4 × SW (T18)	Org.4 × MYC (T19)	Org.4 × Mix (T20)
NPK50	NPK X W (T21)	NPK X SW (T22)	NPK x MyC (T23)	NPK x Mix (T24)
R3				
Control (C)	C x W (T1)	C x SW (T2)	C x MyC (T3)	C x Mix Mix (T4)
Org.1	Org.1 × W (T5)	Org.1 × SW (T6)	Org.1 × MyC (T7)	Org.1 × Mix (T8)
Org.2	Org.2 × W (T9)	Org.2 × SW (T10)	Org.2 × MyC (T11)	Org.2 × Mix (T12)
Org.3	Org.3 × W (T13)	Org.3 × SW (T14)	Org.3 × MyC (T15)	Org.3 × Mix (T16)
Org. 4	Org.4 × W (T17)	Org.4 × SW (T18)	Org.4 × MYC (T19)	Org.4 × Mix (T20)
NPK50	NPK W (T21)	NPK X SW (T22)	NPK x MyC (T23)	NPK x Mix (T24)

2.5. Data recorded

2.5.1. Vegetative Growth Characters

Random samples of six plants from each experimental unit were taken at 65 days after planting and the following measurements were recorded:

- Plant height (PH, cm), it was taken during harvesting by measuring the distance from the base to the tip of the main shoot.

- Number of branches/plant (BN), it was calculated as average number of branches on the marked plants.

- Leaves number per plant (LN), it was calculated as average number of leaves on the marked plants.

- Both total plant fresh weight (FW, g) and total plant dry weight (DW, g) were determined in fresh and after oven-drying the samples at 70 Cº for 48 hours, respectively.

2.5.2. Chemical Constituents

Nitrogen, phosphorus and potassium

Six plants from each plot were taken at random where mature fruits were continuously harvested in suitable maturity stages and then: Estimate the seed mineral contents of nitrogen, phosphorous, and potassium according to [17]; [18] and [19], respectively. However, total uptake of nitrogen, phosphorous, and potassium was calculated according to [20] through the following equation:

$$\text{Uptake of N/P/K (Mg/g d.w)} = \text{nutrient percentage} \times \text{dry matter}$$

Total soluble carbohydrates content

Total soluble carbohydrates were estimated according to [21] by hydrolyzing 0.1 g of the fine powdered leaves with 0.1 N HCl overnight, then in water bath at 100°C for 20 minutes. After cooling the solution, it filtered into 25 ml measuring flask, and completed to mark with distilled water. Total carbohydrates were measured colorimetrically in this solution by the anthrone sulphuric acid method at 630 nm wavelength.

Essential oil (EO) extraction

40 g of harvested fruits were extracted over 3 h through the hydro-distillation method described in [22]. Thereafter, the oil was left to stand undisturbed to assure complete separation in accordance with [23]. EO content was determined via equation:

$$\text{EO content (w/w\%)} = [\text{Extracted EO (g)} / \text{g of the samples}] \times 100$$

Yield attributes

- Umbels number/plant: All umbels on the plant were counted at the fruit ripping stage.

- Total seed yield (kg/fed.): It was calculated from all harvested seeds per plant and then calculated as ton per fed.

2.6. Statistical analysis

The obtained data were subjected to analysis of variance using the procedure illustrated by [24] for a complete randomized block design (CRBD) by statistix 11 statistical software. Means were separated by LSD testing at 5% level.

3. Results and discussion

The study was carried out during the two successive seasons of 2021/22 and 2022/23 at the Experimental Farm of the Botany Department, Faculty of Science, South Valley University, Qena Governorate, Egypt, to study the response of fennel (*Foeniculum vulgare* Mill.) plants for organic and biofertilizers application in comparison to unfertilized treatment (control) for Vegetative growth, *Chemical Constituents*, oil content, Umbels number/plant and seed yield of fennel cultivar "Florence". The study site was Sandy loam soil with low organic matter and fertility. The experiment was carried out in split plot layout as Randomized Complete Blocks Design (RCBD) with three replicates.

3.1. Effect of organic fertilizer applications

Vegetative growth traits

There were significant differences between *organic fertilizer* on fresh vegetative growth parameters (Plant height, number of leaves and number of branches/plant as well as both fresh and dry weights of shoots) in the two studied seasons. Data in Table 4 and Fig. 1 show the effect of organic fertilizer applications on vegetative growth traits such as plant height, number of leaves, number of branches/plant, as well as plant fresh weight (FW, g) and plant dry weight (DW, g) in 2021/2022 and 2022/2023 seasons. The main effect of organic fertilizer application was significant on these vegetative traits of both seasons.

Yield traits

Results in abovementioned Table 4 showed that, there were significant differences between organic application on yield parameters, *i.e.*, umbels number (UN) and seed yield/fed (Y/fed) in the two studied seasons. The main effect of organic fertilizer application was significant in both seasons (Table 10) and its average on both traits. As shown in Table 4 and Fig.2, the best level of organic application in both UN and Y/fed characters was Org.4 (FM, 10 ton/fed) with increment by 172% and 91.4% for Y/fed and UN in descending order over the control followed by Org.2 (Comp, 10 ton/fed) with, mostly, no significant differences between them.

Essential oil content

Results in Table 5 showed that, there were significant differences between organic fertilizer on Essential *oil* content in the two studied seasons. The main effect of organic application was significant on this trait. Fig.3 showed that the best level of organic application in EO was Org.3 (FM, 5 ton/fed), Org.1 (Comp., 5 ton/fed.) and Org.4 (FM, 10 ton/fed) in descending order with increment by 47.5%, 40.7% and 15.7%, respectively over the control (Fig. 3).

Table 3: Analysis of variance for plant growth, yield attributed traits affected by organic and bio-fertilizers as well as their interaction at 1st and 2nd seasons

		PH	NL	NB	FW	DW	UN	Y/P	Y/F
VS	DF	MS, 1st Season							
Reps	2	2.625	0.93	0.39	276.51	1.76	1.35	0.62	1234.95
Org	5	385.43**	489.24**	7.61**	14353.5**	226.4**	39.2**	493.1**	677021**
Error-a	10	9.06	0.30	0.37	75.15	1.44	1.21	0.82	1116.73
Bio	3	124.54**	71.01**	2.50*	1476.27**	3.81**	1.72**	20.37**	203751**
Org×Bio	15	34.63**	33.29**	1.140	1048.05**	0.475	0.118*	1.401	3329.88*
Error-b	36	6.71	0.55	0.78	90.01	0.80	0.33	1.09	1424.27
		MS, 2nd Season							
Reps	2	3.43	1.10	0.89	2.63	0.04	0.88	1.99	1302.52
Org	5	1177.8**	756.29**	8.45**	15834.7**	216.4**	29.09**	371.94**	534365**
Error-a	10	3.114	0.297	0.522	35.64	0.78	0.89	0.73	1191.65
Bio	3	66.27**	22.67**	0.87	647.68**	3.87**	4.16**	32.84**	210748**
Org×Bio	15	437.90**	5.89**	1.41*	776.40**	0.95	0.17	1.76**	5500**
Error-b	36	2.426	0.338	0.639	22.546	0.607	0.352	0.571	1386.72

Table 4: Plant height, number of branches and leaves as well as the weight of both fresh and dry fennel plants in addition to umbels number and seed yield/fed. as affected by organic fertilizers during the two studied years

	PH	NL	NB	FW	DW	UN	Y/F
1st Season							
Control	92.08	21.92	5.75	125.00	5.78	4.17	336.19
Org.1	89.00	27.90	5.50	153.17	6.67	6.62	576.33
Org.2	97.58	35.95	6.56	189.06	14.69	7.37	891.58
Org.3	102.08	23.17	6.67	153.58	13.33	4.50	670.63
Org.4	100.33	35.82	7.41	213.17	17.02	8.33	921.75
NPK50	93.92	36.08	6.75	152.50	12.92	7.41	683.18
LSD	4.266	0.773	0.865	12.287	1.699	1.562	47.366
2nd Season							
Control	87.42	18.58	5.62	118.17	6.46	4.58	332.15
Org.1	85.00	25.92	5.83	150.75	7.08	6.08	494.94
Org.2	95.00	33.33	6.75	198.28	14.17	7.50	864.08
Org.3	109.33	23.25	6.55	146.33	13.67	5.00	619.76
Org.4	101.83	33.33	7.38	216.75	17.50	8.42	895.81
NPK50	89.25	40.25	7.04	143.67	13.67	7.67	679.58
LSD	2.501	0.773	1.024	8.462	1.253	1.338	48.929

Fig.1: Changes percentage of Vegetative growth traits as affected by organic fertilizer (average of both seasons)

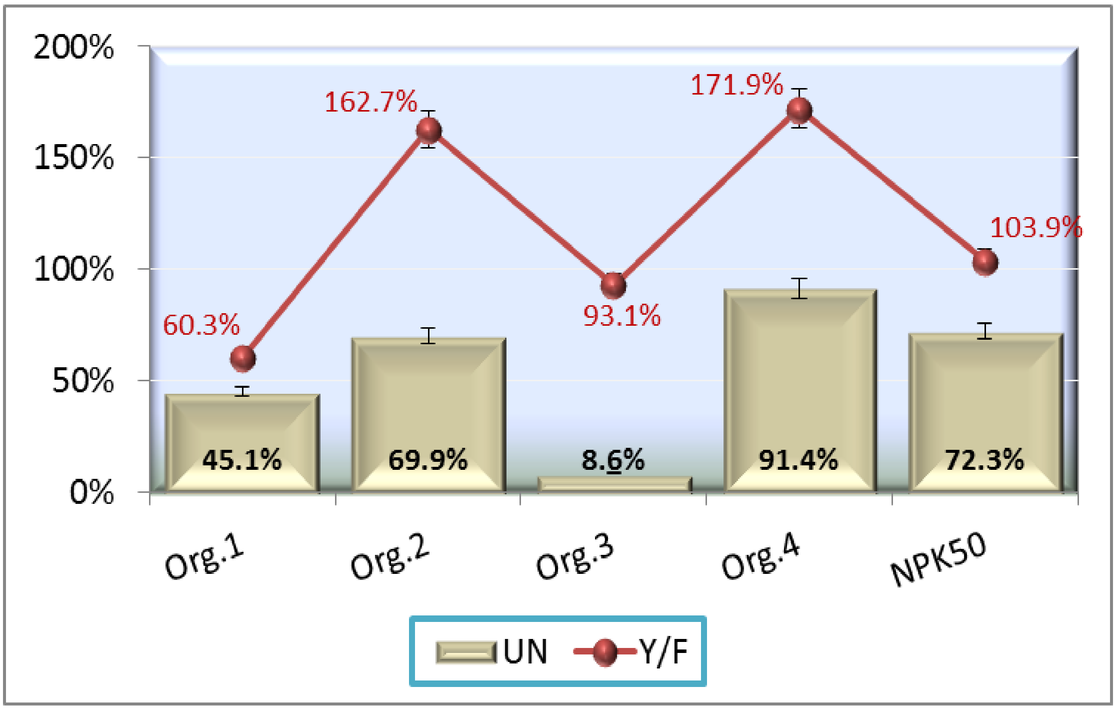


Fig.2: Changes percentage of umbels number and yield traits as affected by organic fertilizer (average of both seasons)

Table 5: Analysis of variance for *Essential oil* content and carbohydrates as affected by organic and bio-fertilizers as well as their interaction in average of two seasons

VS	DF	Oil	Carbohydrates
Blocks	2	0.0007	0.0134
Org	5	0.457**	2.304**
Error-a	10	0.00074	0.00268
Bio	3	0.273**	0.603**
Org×Bio	15	0.009**	0.023**
Error-b	36	0.001	0.00244

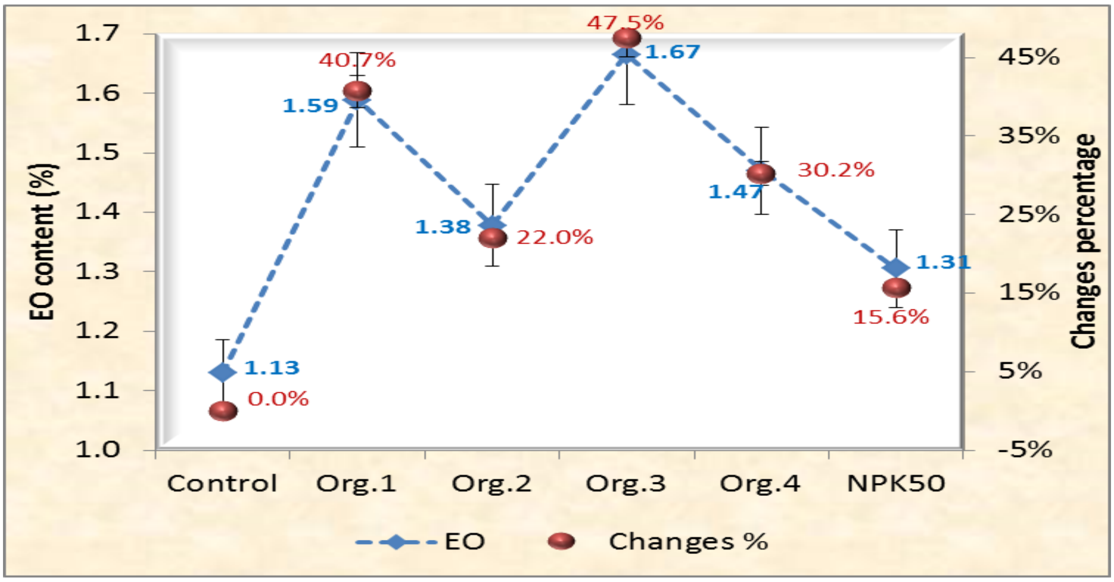


Fig.3: Values and changes percentage of essential oil as affected by organic fertilizer (average of both seasons)

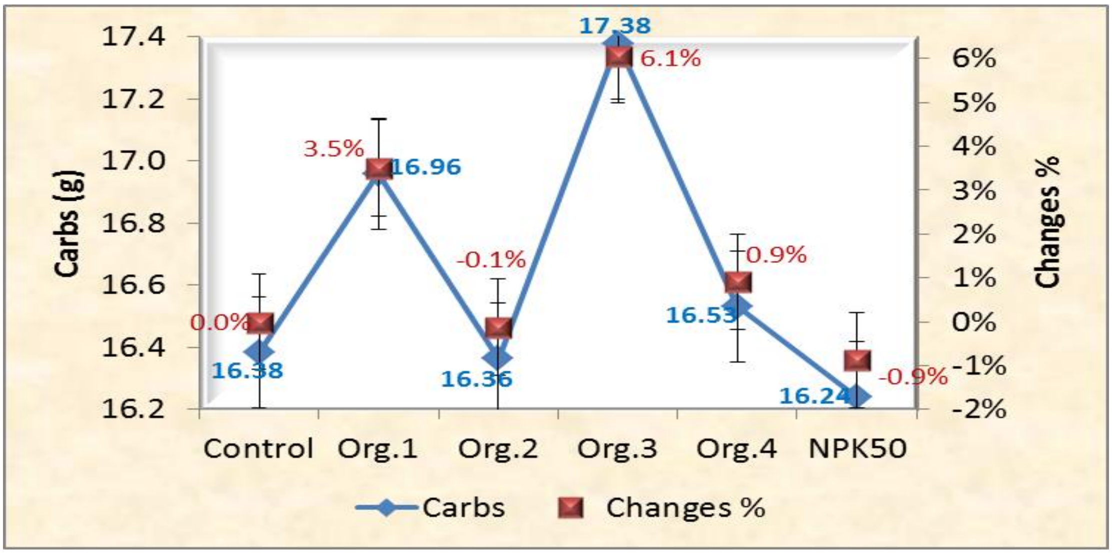


Fig. 4: Values and changes% of carbohydrates (Carbs) as affected by organic fertilizer (average of both seasons).

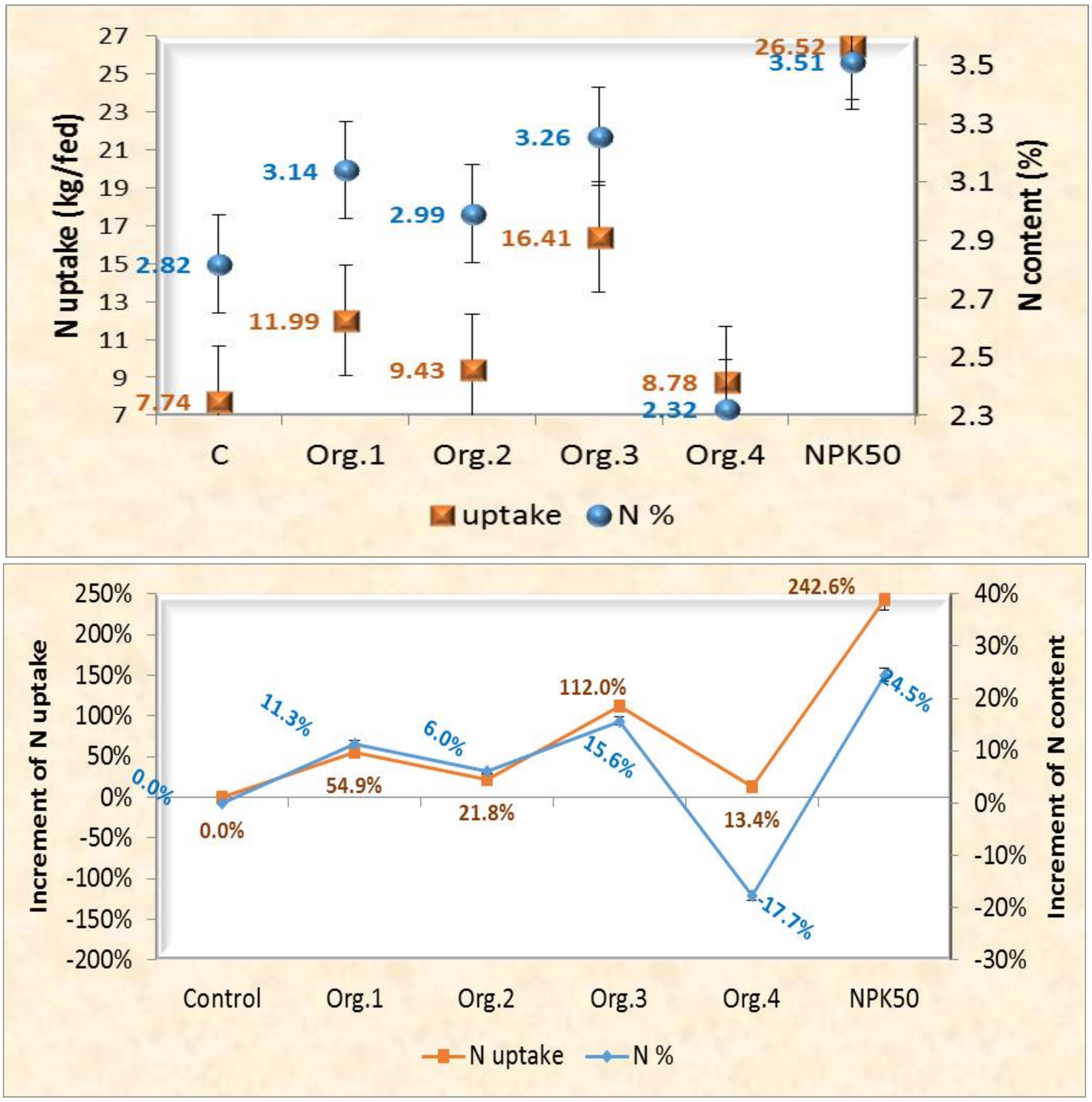


Fig.5: Values (Upper) and changes % (Lower) of N content in leaves and N uptake as affected by organic fertilizer (average of both seasons)

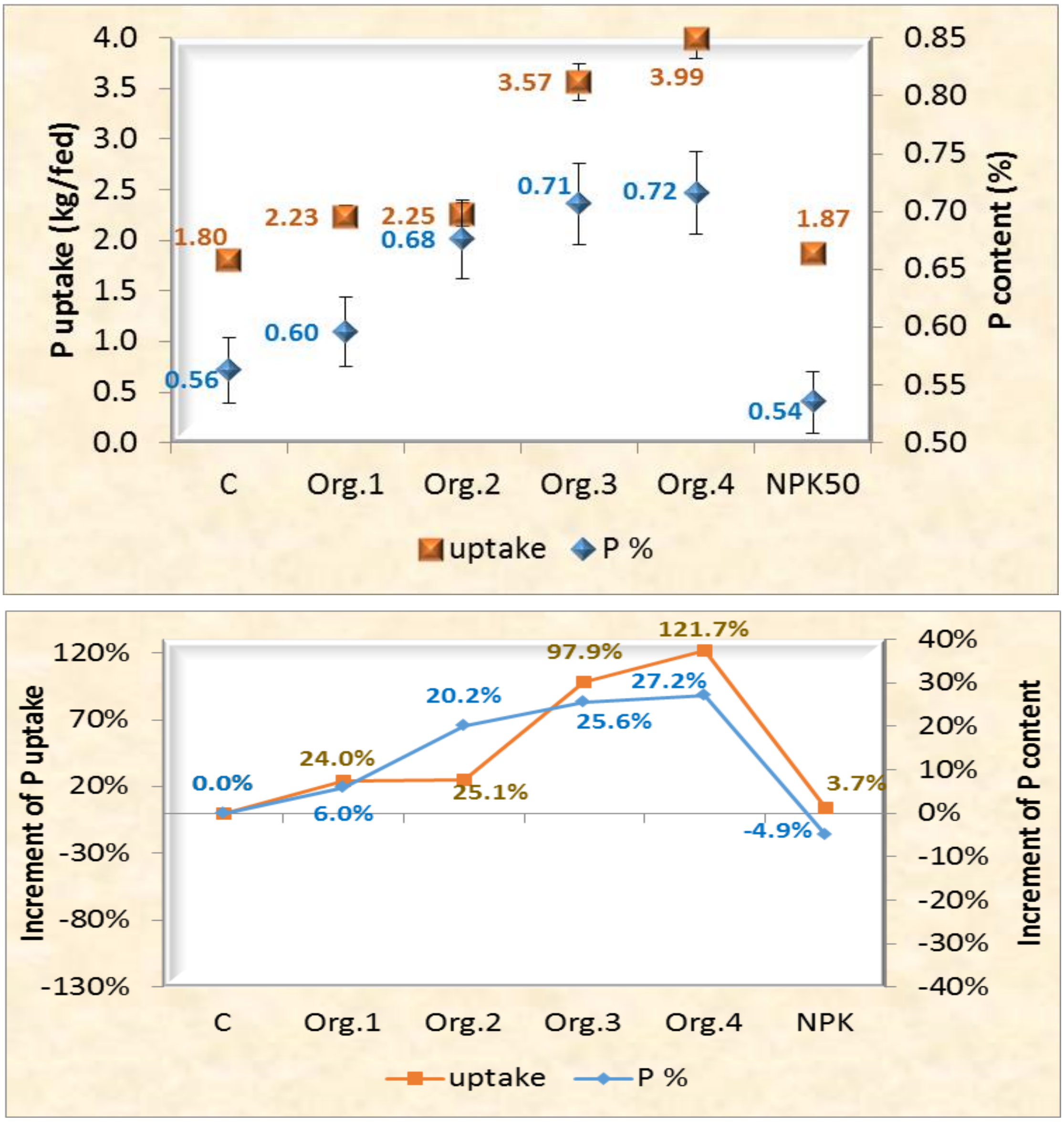
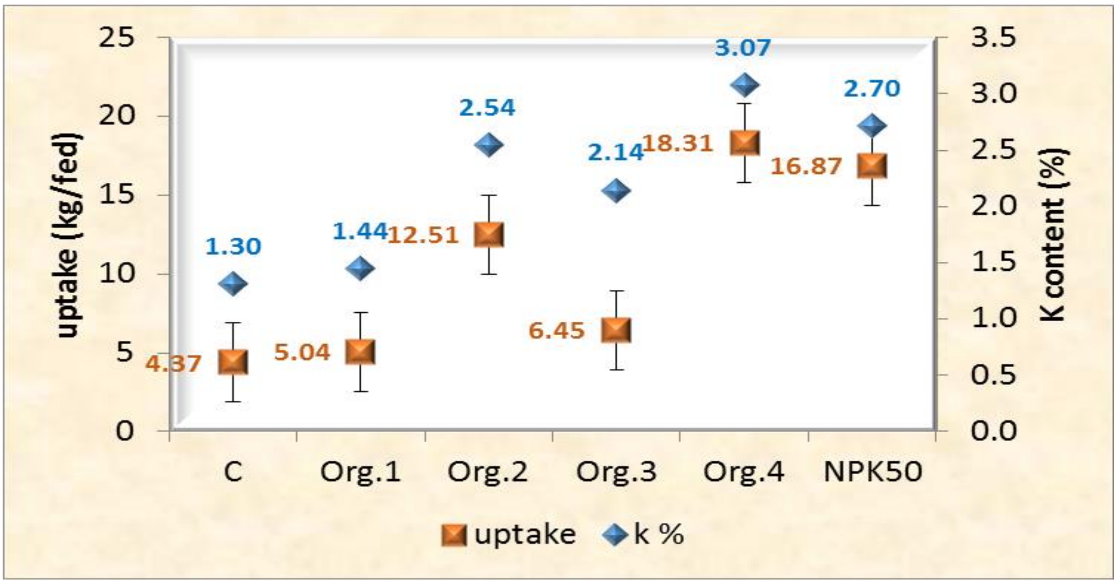


Fig.6: Values (Upper) and changes % (Lower) of P content in leaves and P uptake as affected by organic fertilizer (average of both seasons).



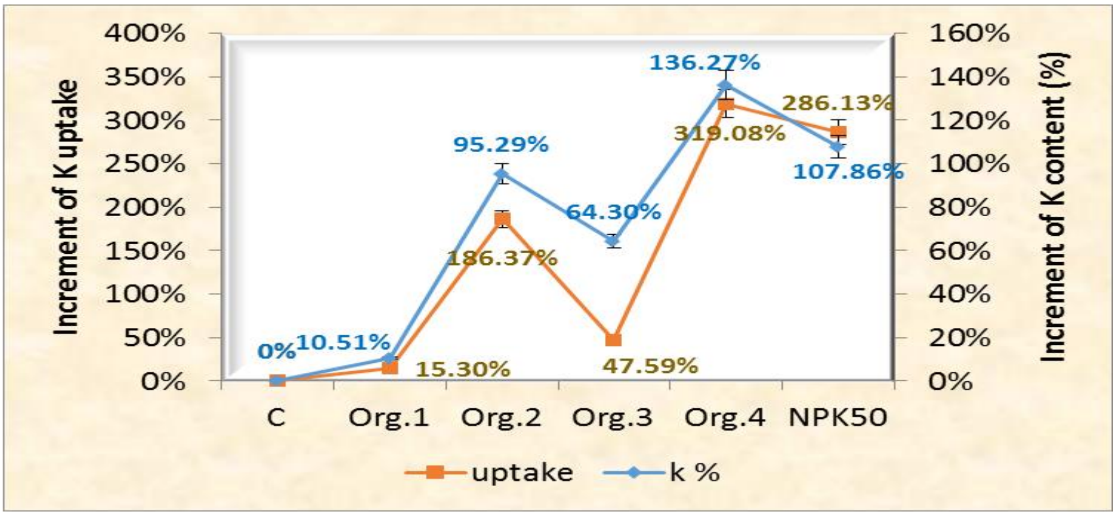


Fig.7: Values (Upper) and changes % (Lower) of K content in leaves and K uptake as affected by organic fertilizer (average of both seasons).

Table 6: Plant height, number of branches and leaves as well as the weight of both fresh and dry fennel plants in addition to umbels number and seed yield/fed. as affected by bio fertilizers during the two studied seasons

	PH	NL	NB	FW	DW	UN	Y/F
1st Season							
Control	91.72	27.17	5.99	149.11	10.56	6.06	529.11
Bio.1	93.33	30.11	6.00	172.61	12.07	6.53	716.25
Bio.2	98.83	31.20	6.87	163.22	11.65	6.14	722.79
Bio.3	99.44	32.08	6.89	172.71	12.67	6.86	751.64
LSD	2.324	0.666	0.794	8.512	0.8	0.514	33.861
2nd Season							
Control	94.56	28.00	6.08	148.61	11.17	6.00	479.74
Bio.1	93.39	29.00	6.39	165.50	12.19	6.33	686.27
Bio.2	92.94	28.78	6.69	165.33	12.11	6.72	703.97
Bio.3	97.67	30.67	6.95	169.86	12.89	7.11	720.89
LSD	1.397	0.522	0.717	4.26	0.699	0.532	33.412

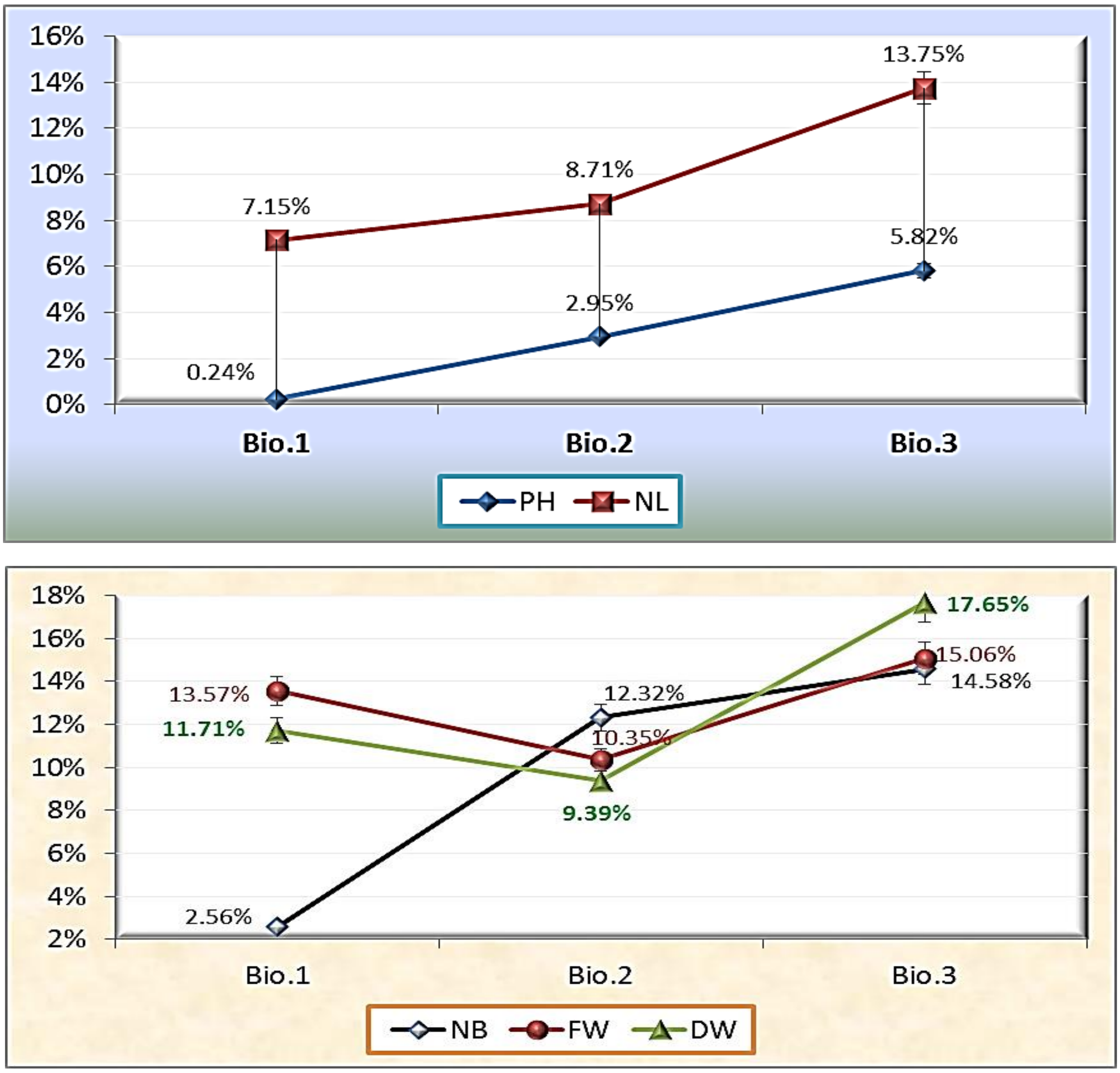


Fig.8: Changes percentage of Vegetative growth traits as affected by bio-fertilizer (average of both seasons)

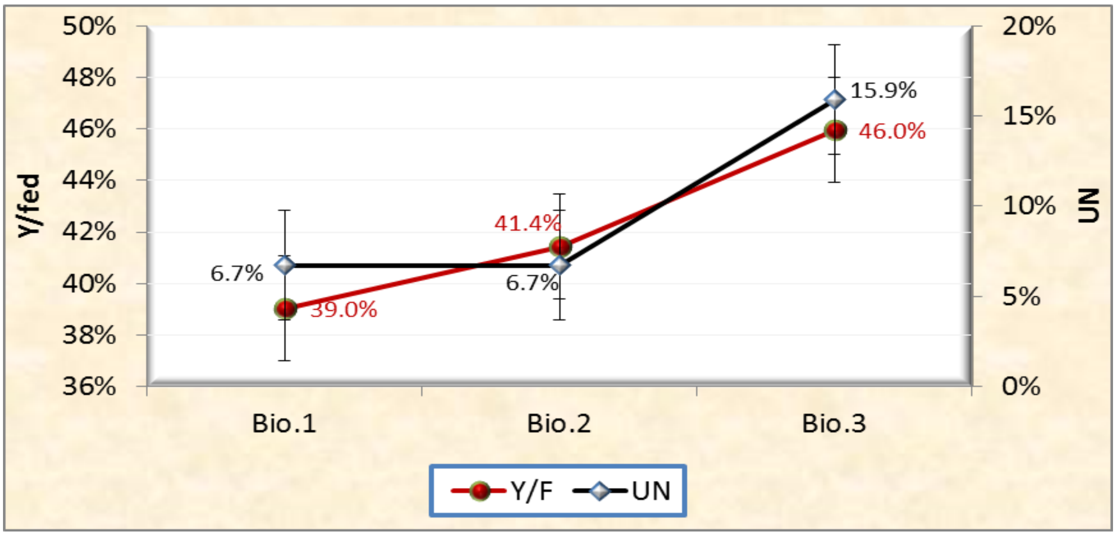


Fig.9: Changes percentage of umbels number (UN) and seed yield/fed (Y/fed) as affected by bio-fertilizer (average of both seasons)

Table 7: Analysis of variance for *Essential oil* content and carbohydrates as affected by organic and bio-fertilizers as well as their interaction in average of two seasons

VS	DF	Oil	Carbohydrates
Blocks	2	0.0007	0.0134
Org	5	0.457**	2.304**
Error-a	10	0.00074	0.00268
Bio	3	0.273**	0.603**
Org×Bio	15	0.009**	0.023**
Error-b	36	0.001	0.00244

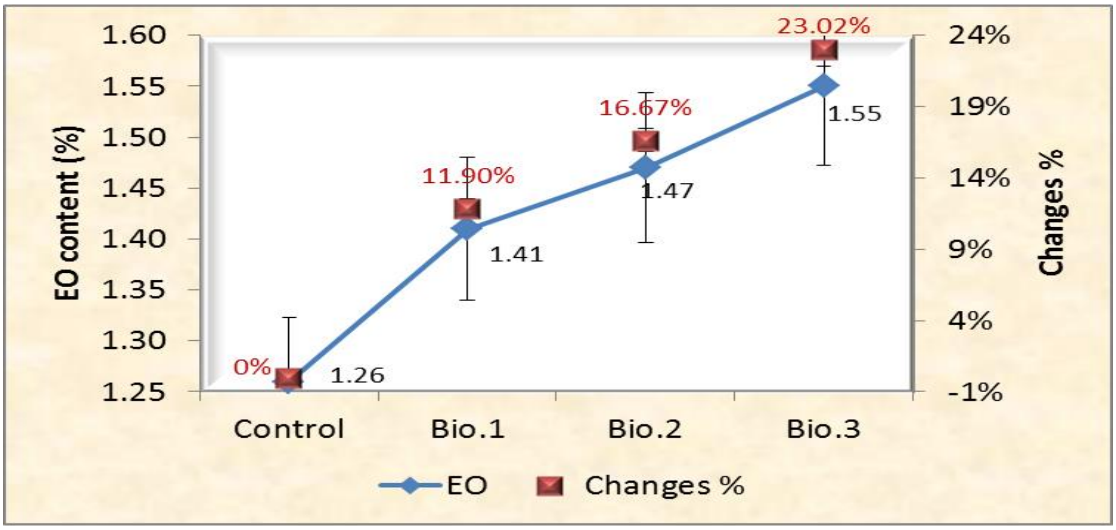


Fig.10A: Content and Changes percentage of Essential oil (EO) as affected by bio-fertilizer (average of both seasons).

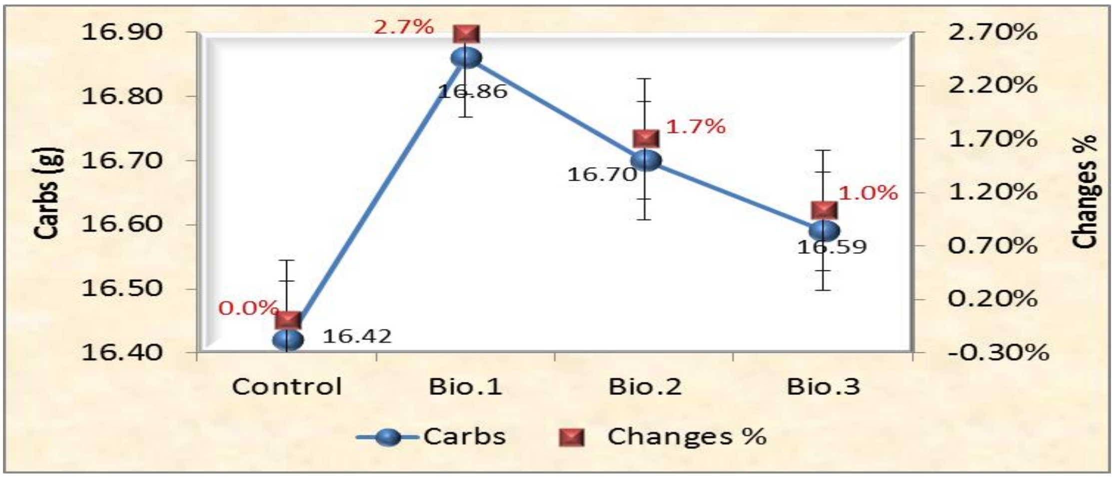


Fig.10B: Content and Changes percentage of carbohydrates (Carbs) as affected by bio-fertilizer (average of both seasons)

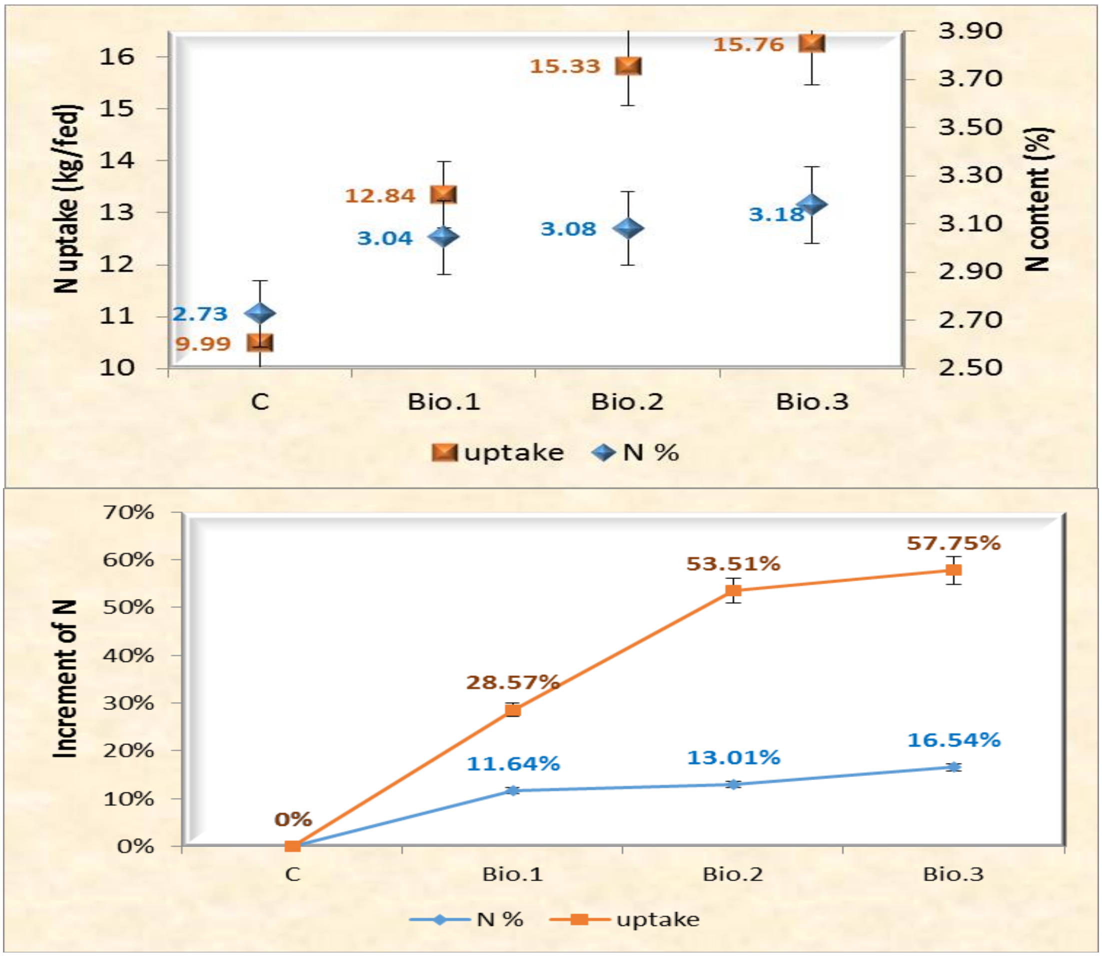


Fig.11: Values (Upper) and changes % (Lower) of N content in leaves and N uptake as affected by bio-fertilizer (average of both seasons).

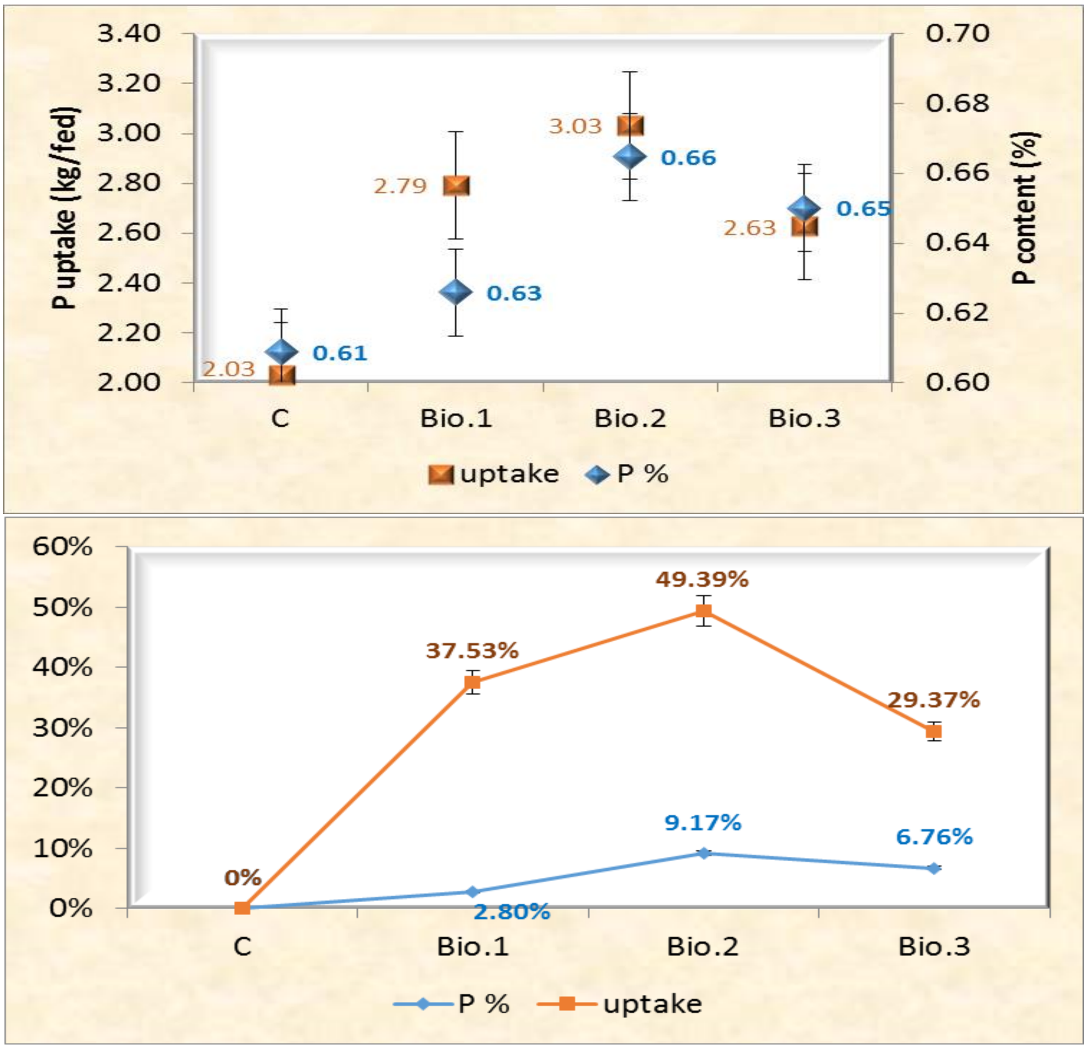


Fig.12: Values (Upper) and changes % (Lower) of P content in leaves and P uptake as affected by bio-fertilizer (average of both seasons).

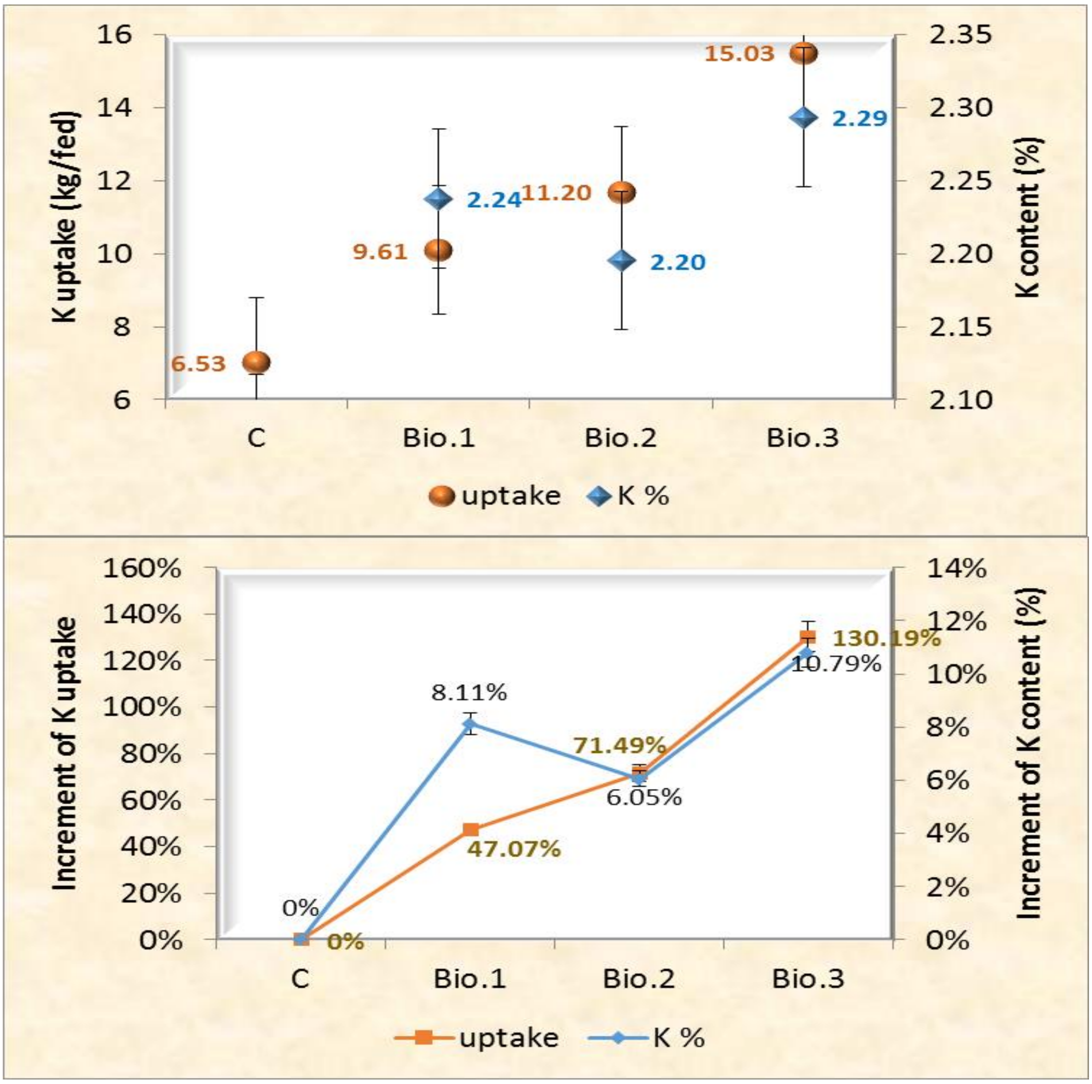


Fig.13: Values (Upper) and changes % (Lower) of K content in leaves and K uptake as affected by bio-fertilizer (average of both seasons).

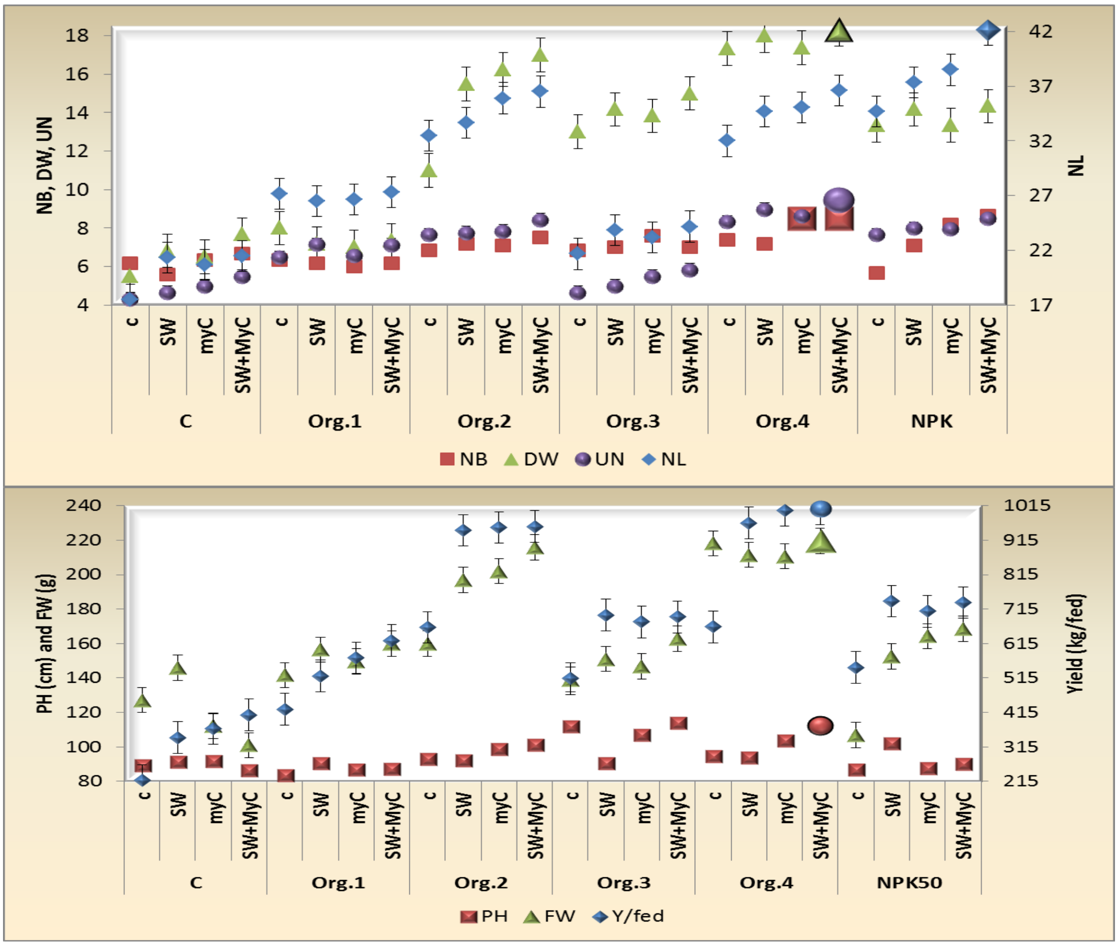


Fig. 14: Dual interaction effect of organic (Main-plot) and bio-fertilizer (sub-plot) application on vegetative traits, UN and seed yield of fennel plants

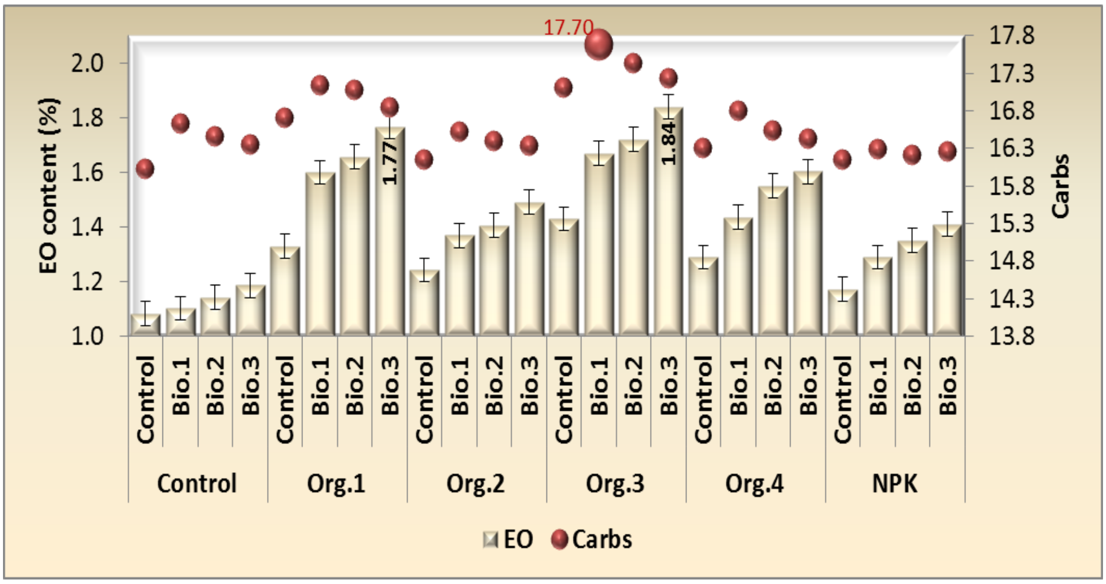


Fig. 15: Dual interaction effect of organic (Main-plot) and bio-fertilizer (sub-plot) application on essential oil and leaves carbohydrates traits of fennel plants

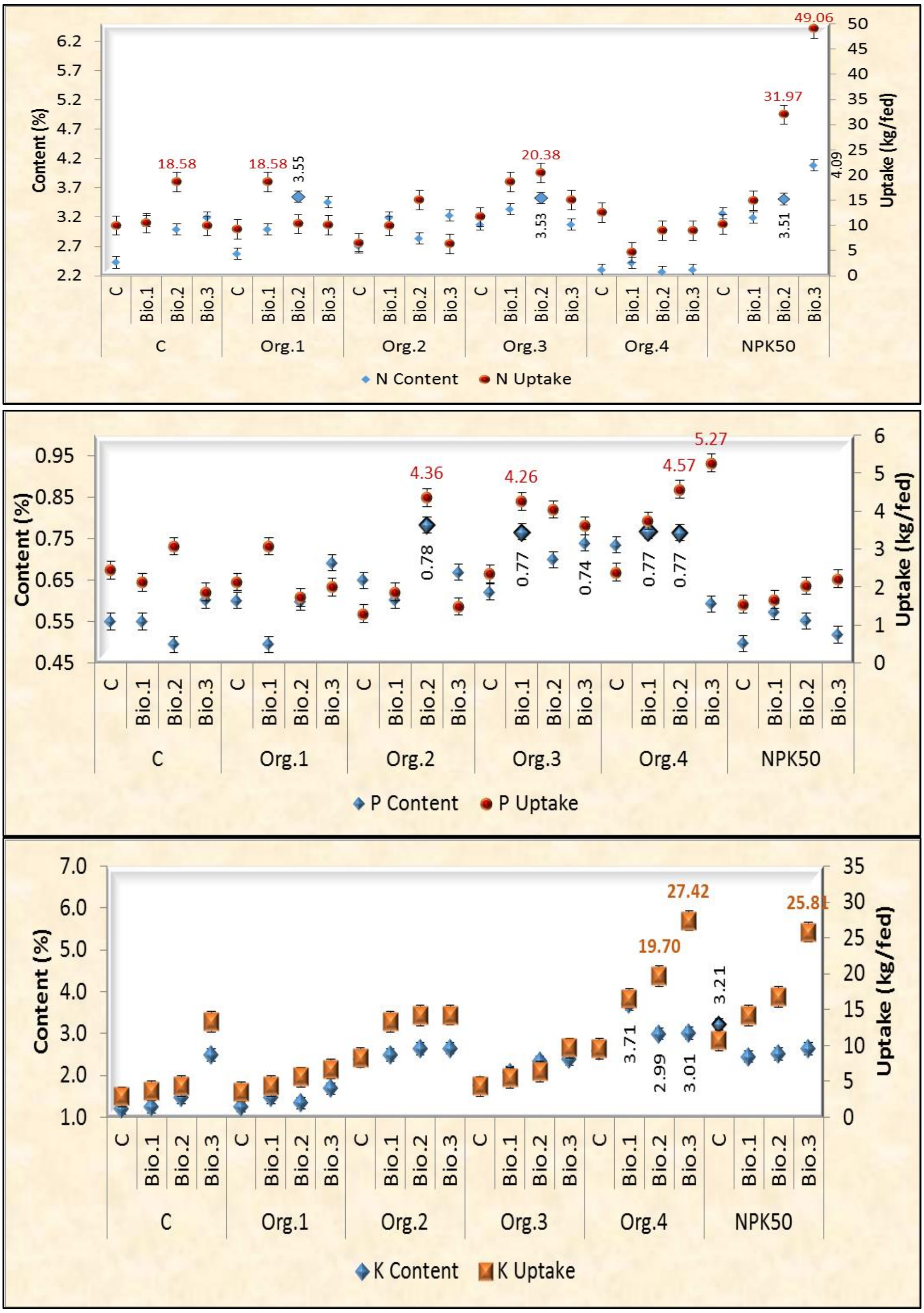


Fig. 16: Dual interaction effect of organic (Main-plot) and bio-fertilizer (sub-plot) application on NPK contents (%) and uptakes (kg/fed) traits of fennel plants

Carbohydrates content in leaves

Results in Table 5 and Fig.3 showed that, there were significant differences between organic application on carbohydrates (Carbs). The best level of organic application in Carbs characters was Org.3 (FM, 5 ton/fed), Org.1 (Comp., 5 ton/fed.) and Org.4 (FM, 10 ton/fed) in descending order with increment by 6.07%, 3.51 and 0.91%, respectively over the control. The increase in the vegetative studied characters may be reflect the improvement physiological, biological and chemical soil properties along with the increase water holding capacity and available plant water and nutrient by application organic fertilizer, *i.e.,* filter mud applications or compost. Many authors reported that added organic fertilizer to soil increases all vegetative growth traits [25,26,27,28].

Nitrogen *content (N%) and uptake (kg N/fed)*

Data in Fig. 5 show the effect of organic fertilizer applications on *nitrogen* (N) content and uptake in average of 2021/2022 and 2022/2023 seasons. The superiority treatment of organic fertilizer application in N% character was NPK treatment followed by Org.3 and Org.1with no significant differences between them. They increment by 24.5% (NPK), 15.6 % (Org.3) and 11.3 % (Org.1) over the control in descending order (Fig.5). Whereas, the lowest significant value was obtained by both control and Org.4 treatments. As for N uptake, the superiority treatment of organic fertilizer application was also, NPK treatment followed by Org.3 and Org.1. They increment by 242.6% (NPK), 112.0 % (Org.3) and 54.9 % (Org.1) over the control in descending order (Fig.5).

Phosphorus content (P%) and uptake

Data in Fig. 6 show the effect of organic fertilizer applications on *Phosphorus* (P) content and uptake in average of 2021/2022 and 2022/2023 seasons. The superiority treatment of organic fertilizer application in P% character was Org.4 (0.72%) followed by Org.3. (0.71). No significant differences between Org.1 and Org.2 and also, between Org.3 and Org.4. Whereas, the lowest significant value was obtained by both control and NPK treatments. They increment by 27.2% (Org.4), 25.6 % (Org.3), 20.2% (Org.2) and 6% (Org.1) over the control in descending order (Fig.6). As for P uptake, the superiority treatment of organic fertilizer application in P% character was Org.4 (3.99 kg/fed) followed by Org.3. (3.57 kg/fed). No significant differences between Org.1 and Org.2 and also, between control and NPK treatments. Whereas, the lowest significant value was obtained by both control and NPK treatments. They increment by 121.7% (Org.4), 97.9 % (Org.3), 25.1% (Org.2) and 24% (Org.1) over the control in descending order (Fig.6).

Potassium content (K%) and uptake (kg K/fed)

Data in Fig. 7 show the effect of organic fertilizer applications on *Potassium content (K%) and uptake (kg K/fed)* in average of 2021/2022 and 2022/2023 seasons. The superiority treatment of organic fertilizer application in P% character was Org.4 (3.07%) followed by NPK (2.7%), Org.2. (2.54%) and Org.3 (2.14%). No significant differences between NPK50 and Org.2 and also, between control and Org.1. Whereas, the lowest significant value was obtained by both control and Org.1 treatments. They increment by 136.3% (Org.4), 107.9 % (NPK), 95.3% (Org.2) and 64.3% (Org.3) over the control in descending order (Fig.7). As for K uptake, the superiority treatment of organic fertilizer application in P% character was Org.4 (18.31%) followed by NPK (16.87%), Org.2. (12.51%) and Org.3 (6.45%). Whereas, the lowest significant value was obtained by both control and Org.1 treatments with no significant differences between them. They increment by 319.1% (Org.4), 286.1 % (NPK), 186.4% (Org.2) and 47.6% (Org.3) over the control in descending order (Fig.7). These results are in agreement with [29] who found that organic application enhanced mineral content.

3.2. Effect of Bio-fertilizer applications

Vegetative growth traits

There were significant differences between Bio-fertilizer on fresh vegetative growth parameters (Plant height, number of leaves and number of branches/plant as well as both fresh and dry weights of shoots) in the two studied seasons (Table4). As shown in Table 6, No significant differences between Bio.1 (SW) and Bio. 2 (myC) for all fresh and dry vegetative traits in both seasons except fresh weight of shoots in 1st season. The superiority treatment of bio-fertilizer application in all vegetative growth studied characters was Bio.3 (SW+MyC) with increment by 17.65%, 15.06%, 14.58%, 13.75% and 5.82% for dry weight, fresh weight, number of branches, number of leaves and plant height in descending order over the control (Fig.8).

Yield traits

Results in Tables 4 and 6 showed that, there were significant differences between biofertilizer application on umbels number (UN) and seed yield/fed (Y/fed) in the two studied seasons. No significant differences between Bio. 1 (SW) and Bio.2 (myC) were observed for umbels number and seed yield (plant and fed.) in both seasons. As shown in Table 6 and Fig. 9, the superiority treatment of bio-fertilizer application in umbels number and per feddan of fennel plants was Bio.3 (SW+MyC) with increment by 15.9% and 45.06%, respectively over the control.

Essential oil content

Results in Table 7 showed that, there were significant differences between biofertilizer application on oil content (EO) in the average of two studied seasons.

Carbohydrates content in leaves

Results (Table 7) showed that, there were significant differences between bio-treatments on carbohydrates (Carbs) in the two studied seasons.The best level of organic application (Fig.10) in Carbs characters was Bio.1 (SW) and Bio.2 (MyC) with increment by 2.68% and 1.71%, respectively over the control. Fig. 10 exhibited that the best level of organic application in EO was Bio.3 (SW+MyC) with increment by 23.02% over the control.

Nitrogen content and uptake

Data in Fig. 11 shows the effect of Bio-fertilizer applications on nitrogen (N) content and uptake in average of 2021/2022 and 2022/2023 seasons. The superiority treatment of bio-fertilizer application in N% character was Bio.3 (3.18% Mix treatment) followed by Bio.2 (3.08%, MyC) and Bio.1 (3.04%, SW) with no significant differences between MyC and SW. They increment by 16.5% (MyC+SW), 15.6 % (MyC) and 11.3 % (SW) over the control in descending order (Fig.11). Whereas, the lowest significant value was obtained by control treatment. As for N uptake, the superiority treatment of bio-fertilizer application was also, Mix treatment (Bio.3) followed by Bio.2 and Bio.1. They increment by 58.8% (Mix), 53.50 % (Bio.) and 28.6 % (Bio.1, SW) over the control in descending order (Fig.27).

Phosphorus content and uptake

Data in Fig. 12 show the effect of Bio-fertilizer applications on Phosphorus (P) content and uptake in average of 2021/2022 and 2022/2023 seasons. The superiority treatment of bio-fertilizer application in P% character was Bio.2 (0.66%, MyC) followed by Bio.3 (0.65%, Mix) and Bio.1 (0.63%, SW) with no significant differences between the three bio-treatments. They increment by 9.2% (MyC), 6.8 % (Mix) and 2.8 % (SW) over the control in descending order (Fig.12). Whereas, the lowest significant value was obtained by control treatment. As for P uptake, the superiority treatment of bio-fertilizer application was also, MyC treatment (Bio.2) followed by Bio.1 (SW) and Bio.3 (Mix) with no significant differences between Bio.1 and Bio.3. They increment by 49.4% (MyC), 37.5 % (SW) and 29.4 % (Mix) over the control in descending order (Fig.12).

Potassium (K) content and uptake

Data in Fig. 13 shows the effect of Bio-fertilizer applications on Potassium (K) content and uptake in average of 2021/2022 and 2022/2023 seasons. The superiority treatment of bio-fertilizer application in K% character was Bio.3 (2.29%, Mix) followed by Bio.1 (2.24%, SW) and Bio.2 (2.2%MyC) with no significant differences between them. They increment by 10.8% (Mix), 8.1 % (SW) and 6.1 % (MyC) over the control in descending order (Fig.13). Whereas, the lowest significant value was obtained by control treatment. As for K uptake, the superiority treatment of bio-fertilizer application was also, Mix treatment (Bio.3) followed by Bio.2 (MyC) and Bio.1 (SW) with no significant differences between Bio.1 and Bio.2. They increment by 130.2% (Mix), 71.5 % (MyC) and 47.1 % (SW) over the control in descending order (Fig.13). These results are in agreement with [29] who found that organic application enhanced mineral content.

3.3. Effect of the interactions

The interacted Org. 4× Bio.3 treatment applications (Fig. 14) exhibited the highest significant effects on most vegetative growth traits and yield traits with increment percentage by 361% (Y/fed), 256.67% (DW), 135% (UN), 109.05% (NL), 72.61% (FW), 48.15% (EO) 41.18% (NB), 26.17% (PH) and 2.49% (Carbs) in descending order comparing with the general control (without Org. or Bio. application). However, the combinations of Org. 3× Bio.3 and Org. 3× Bio.1 treatments application (Fig.15) exhibited the highest significant effect on Essential oil content and Carbohydrates content with increment percentage by 69.9% and 10.33%, respectively comparing with the general control (without Org. or Bio. application). By comparing the effect of different treatments on the three elements of nitrogen (N), phosphorus (P) and potassium (K) as shown in Fig.16, it was found that the Org.3×Bio.2 treatments was preferred to achieve a reasonable and proportional increase in the provision of the three elements at any stage of growth, with an increase of 45.4, 27.1 and 93% NPK contents and 104.8, 64.9 and 124.3% uptake for N, P and K, respectively.

4. General discussion and conclusion

Compost and other organic materials can increase soil structure, root development, plant nutrient provision, and plant nutrient uptake, as shown by [30]. Additionally, compost helps the soil absorb and hold onto water, which benefits plant growth and important oil components. According to [31], plants treated with a combination of compost and microorganisms produced the maximum essential oil of rosemary (*Rosmarinus officinalis* L.). They proposed that their enhancing effect on vegetative growth characteristics and plant chemical composition, including nitrogen, phosphorus, potassium, and total carbohydrates of rosemary, which can affect the yield of fennel and essential oil, may be the reason for the stimulative positive impact of this treatment on increasing essential oil. The amount and quality of the fennel seed and its essential oil were found to be positively impacted by compost, filter mud, and various biotreatments (Seaweed and/or mycorrehiza). Additionally, the combination of filter mud or compost with the mix bio-treatment had a greater impact on yield and vegetative attributes. In general, it appears that biological and organic fertilizers can be regarded as a good alternative to chemical fertilizers when creating systems for the sustainable production of medicinal plants.

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