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Influence of Plant Density and Fertilization Treatments on Growth and Productivity of Caraway (*Carum carvi*, L.) Plants

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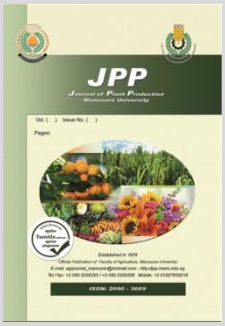

ABSTRACT

The present investigation was conducted during two consecutive seasons 2019/2020 and 2020/2021 in the experimental farm of Horticultural Research Station at Sids, Beni-Suef Governorate. Such study aimed to investigate the response of caraway plants to plant density and some fertilization treatments in terms of vegetative growth (plant height, stem diameter, number of branches and herb dry weight), yield parameters (number of umbels and fruit yield per plant & per fed.), oil yield productivity (oil% and yield per plant & per feddan) and NPK%. The examined plant density treatments included three planting distances (60, 40 and 20 cm) while, fertilization treatments included five rates of each of NPK, Vermicompost powder (VC1, 2) at 200, 300 Kg/fed, Vermicompost liquid (VCL1, 2) at 100, 150 liter/fed. The experiment was arranged in a split-plot design. The best values of fruit and oil yield/ fed were obtained due to planting caraway plants to high plant density. Concerning fertilization treatments, all of the prementioned growth, fruit and oil yield traits were considerably augmented due to NPK followed by VCL2, VC2 while VCL1, VC1 gave the least values. In regard to the interaction gave between the, two involved factors, the highest fruit and oil yield values were given by fertilizing caraway plants with the NPK with planting distances of 20 (cm) between each hill. It is advisable, from the economical and environmental point of view, to fertilize caraway plants with VCL at 150 liter/fed or VC at 300 Kg/fed to improving caraway plants productivity.

Keywords: Caraway, Plant density, Vermicompost, Essential oil

INTRODUCTION

Caraway (*Carum carvi* L.) is an umbelliferous crop (belongs to family of Apiaceae) native to Europe, Asia, and North Africa. It produces schizocarps, which are seeds with distinctive flavor and aroma (Iacobellis *et al.* 2005). It considered one of the most important medicinal and aromatic plants grown in Upper Egypt. The economical importance of caraway plants is attributed to its fruits which contain approximately 1-6% volatile oil, with carvone and limonene as the principal components. The *Carum carvi* seeds, contain lipids (13-21%), nitrogen compounds (25-35%), fiber (13-19%) and water (9-13%) (Kocourkova *et al.* (1999). The seeds are also rich in a variety of fatty acids, including petroselinic acid, an uncommon but crucial industrial monounsaturated fatty acid (MUFA), linoleic, oleic, and palmitic acid (Ngo-Duy *et al.* 2009). Due to its specific antifungal, antibacterial, and antioxidant qualities, caraway essential oil is used in a wide variety of products in the pharmaceutical, health care, and cosmetics industries. (Iacobellis *et al.* 2005; Vallverdú-Queralt *et al.* 2015).

Many investigations in the field of agricultural practices still needed in order to maximize fruits and oil yield of Caraway plants under different environmental conditions. They practice organic fertilization (vermicompost) under Beni- Suef Governorate conditions and plant density. Plant establishment, growth, fruit yield, and oil yield are all affected by density, Singh (2004) on rosemary studied the effect of plant spacing at (30, 45, and 60 cm), and found that the higher total herbage yield was obtained at closer spacing compared with wider spacing. Olcay Arabaci and Emine Bayram (2004) cultivated *Ocimum basilicum* with various plants densities (20, 40 and 60 cm), and found that the highest green herb yield was obtained from the density of 20 cm compared with wider spacing. Hafez (1998) on black cumin found that reducing plant density caused considerable increase in vegetative growth characters, seed and oil yield per plant.

Substitution of chemical fertilizers by the organic material is very important for sustainability of agriculture production and maintain of soil fertility (Parakash and Prasad, 2000). Vermicompost is an organic fertilizer in the form of worm dung dried. The decomposition of organic matter occurs due to the interaction of microorganisms with earthworms (Lesufi 2015). The main value of vermicompost as an organic manure has been well recognized for utilizing in agriculture as it contains valuable nutrients, inorganic form besides being a very effective soil ameliorant (Vijayalakshmi *et al.* 2006). Earthworms activity is found to enhance the beneficial microflora and suppress harmful pathogenic microbes. A substantial source of micro- and macronutrients as well as microbial enzymes is found in soil wormcasts. (Lavelle and Martin 1992). Vermicompost tea is rich in mineral elements than commercials plant growth media. These mineral elements are available in standard forms that could be taken up by the most cultivated plants, crops and their forms like soluble N, P, K, Ca and Mg as well as some plant growth promotions regulate such as auxins, gibberellins and cytokinins (Arancon *et al.* 2005 and Javed *et al.* 2017).

Recently, unusual efforts are used to replacing chemical fertilizers with organic products for medicinal and aromatic plants to obtain safe production besides reducing production costs and environmental pollution without reduction of yield. Therefore, the objective of this study was

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to substitute chemical fertilizers (NPK) with some organic products such as vermicompost to achieve safe caraway production under the conditions of plant density.

MATERIALS AND METHODS

The present investigation was conducted in the experimental farm and laboratory of the Horticultural Research Station at Sids, Beni-Suef Governorate, during 2019/2020 and 2020/2021 seasons to study effect of NPK, vermicompost (VC) and vermicompost liquid (VCL) treatments on vegetative growth, fruit yield and essential oil parameters of caraway plants.

Local *Carum carvi* seeds obtained from Sids Agricultural Research Station, Dept. of Medicinal and Aromatic Plants. Hort. Res. Inst., Agric. Res. Center, Egypt. Seeds were sown on the first week of November of both seasons in 3.00 x 3.60 meter plots with 60 cm distance between the rows and three distances (20, 40 and 60 cm) between hills within each row. The plants were thinned to 2 plants / hill after one month of sowing. Physical and chemical properties of the soil are shown in Table (1), according to, Jackson, 1973.

Table 1. Physical and chemical analysis of the soil.

Particle size distribution*			Textural Class	Chemical properties**								
Clay %	Silt %	Sand %		OM %	EC, dSm^{-1} (at 25°C)	Available (ppm) N	P	K	Fe	Zn	Mn	pH
47.70	32.20	20.10	Clay	1.45	1.15	38.00	12.70	254.6	2.15	0.28	0.58	7.7

A complete randomized block design following the split- plot arrangement, in three replicates, was executed in this experiment with three plant densities in the main plots (A) i.e. (70000, 35000 and 23000 plants /fed, which obtained by planting on ridges 60 cm width and 20, 40 and 60 cm between hills, correspondingly).

The sub- plots (B) included six treatments as follows:

- Control (zero fertilization).
- Mineral fertilization of NPK
- Vermicompost powder (VC1) at 200 Kg/fed.
- Vermicompost powder (VC2) at 300 Kg/fed.
- Vermicompost liquid (VCL1) at 100 liter/fed.
- Vermicompost liquid (VCL2) at 150 liter/fed.

The mineral N, K and also VC fertilizers amounts, for each treatment were divided into 3 batches and added after the last thinning and every three weeks thereafter. While phosphorus fertilizer was added during soil preparation. The two vermicompost liquids treatments were divided to the soil, the first dose of VCL (dilution 1: 5 tap water) was applied after 45 days from sowing date and repeated two times at 15 days intervals through the both growing season.

The dose of mineral NPK was added at the rate of 200 Kg/ fed ammonium nitrate, 33.5%N; 150 Kg/ fed calcium superphosphate, 15.5% P2O5 and 100 Kg/ fed potassium sulphate, 48.55 K2O. The physical and chemical properties of vermicompost powder (commercial product of VERMI UPPER EGYPT) are shown in Table (2), while the vermicompost liquid was used that contains the following properties: Organic Matter (3.56%), pH 7.15, E.C **dSm^{-1}** (44.7) and total percentages of NPK (1.74, 0.51,6.43) respectively.

Table 2. Physical and chemical properties of vermicompost (powder).

Properties	Value	Properties	Value
Fresh weight of 1 m^3	832kg	Org. Carbon%	11.14
Organic Matter	19.22%	Ash %	80.78
Moisture (%)	30:33	Total P %	2.83
pH (1:10)	7.5	Total K %	0.67
E.C. **dSm^{-1}**	1.74	Total N %	1.1

Data were recorded for plant height (m), stem diameter (cm), Branches number/ plant, herb dry weight (g/plant), number of umbels/ plant, fruit yield (g/ plant and Kg/ fed), Essential oil % of fruits and Essential oil yield (ml/ plant and l/ feddan). The three volatile oil parameters according to the method of Gad *et al.* (1963). In addition herb N, P and K% were determined according to Wilde *et al.* (1985), Chapman and Pratt (1975) and Cottenie *et al.* (1982), respectively. Obtained data were statically analyzed following the L.S.D. method at 5% according to MSTAT-C (1986).

RESULTS AND DISCUSSION

I) Vegetative growth characters:

Data obtained in Table (3) indicated that the four tested vegetative growth characters, plant height (m), stem diameter (cm), branches number/ plant and herb dry weight/ plant (g/ plant) were significant on all growth characteristics, in both seasons, due to the differences between the studied three planting distances, i.e. 60, 40 and 20 cm. The plant height of caraway plants was gradually increased by increasing plant density in the two seasons as shown in table (3). Significant differences were obtained between the high planting density (20 cm Planting distance) and the low one, (60 cm Planting distance). On the other hand, stem diameter, number/ branched and herb dry weight were gradually decreased by increasing plant density in the two successive seasons. These results were in agreement with those obtained by Abbas (2014) on *Ocimum basilucum*, El-Metwally *et al.* (2017) on faba bean, Gabisa *et al.* (2017) on *Arachis hypogaea* and Onat *et al.* (2017) on the same plant *Arachis hypogaea*. In regard to plant density, it is well known that narrow planting distances results in more competition between plants for water, soil, nutrients and light in comparison with low density such low planting density supplies the plants with more room for root system growth and adequate nutrients, water and light, thereby produces thicker and stronger stems with more and well-branched plants capable of holding more umbels, with higher fruit yield/ plant. In this connection, Thalji (2006), demonstrated that narrow spacing, in their works, lead to a reduction of light.

Table (3) shows that the five fertilization treatments (NPK, vermicompost (VC1) at 200 Kg/fed, vermicompost (VC2) at 300 Kg/fed, vermicompost liquid (VCL1) at 100 liter/fed and vermicompost liquid (VCL2) at 150 liter/fed) increased the four studied parameters, plant height, stem diameter, branches number/ plant and herb dry weight/ plant, with significant differences for the all fertilization traits in comparison with control treatment in both seasons. The highest values, for the four tested parameters, were obtained from the NPK treatment, followed by vermicompost liquid at 150 l/fed then vermicompost (VC2) at 300 Kg/fed, while VC at 200 Kg/fed and VCL at 100 l/fed treatments gave the least values and these results were almost identical in both first and second seasons. It was interesting to find out that such three superior treatments were statistically equal, in both season, in giving the tallest plants, thickest stems, more branches number and heaviest herb dry weight/ plant.

The role of NPK and organic fertilization in augmenting vegetative growth traits was also observed by Badran *et al.* (2011)

on coriander plants, Sardoei *et al.* (2014) on African Marigold (*Tagetes erecta*), Vinutha *et al.* (2017) on sorghum plants and Ramnarain *et al.* (2018) on *Brassica rapa.* The superiority of mineral NPK fertilization could be attributed to the unique biological and physiological roles. Nitrogen is a constituent of most organic compounds i.e. amino acids, nucleic acids such as (DNA and RNA), vitamins, phosphatides, enzymes, alkaloids, purine, and many energy transfer materials such as chlorophylls, ADP and ATP, Bidwall (1974). Increased growth and production with higher vermicompost levels may also be attributed to enhanced nutrient uptake and assimilation. Atiyeh *et al.* (2000). These results confirming those obtained by Rogelio (2017), whom mentioned that application of vermicompost tea could be used as an alternative growth enhancers of sweet corn considering that it improves the vegetative growth of plants such as plant height and stem diameter.

Table 3. Effect of plant density and fertilization treatments on vegetative growth characters of caraway plants during two seasons 2019/2020 & 2020/2021.

Fertilization (B)	Plant Density (A) "Planting distance"							
	Planting distance 60 (cm)	Planting distance 40 (cm)	Planting distance 20 (cm)	Mean (B)	Planting distance 60 (cm)	Planting distance 40 (cm)	Planting distance 20 (cm)	Mean (B)
	First season 2019/ 2020				Second season 2020/ 2021			
	Plant height (m)							
Control	0.98	1.07	1.11	1.05	0.96	1.13	1.17	1.09
NPK	1.21	1.25	1.28	1.25	1.19	1.28	1.32	1.26
VC1	1.10	1.12	1.18	1.13	1.12	1.15	1.19	1.15
VC2	1.15	1.22	1.25	1.21	1.18	1.23	1.27	1.23
VCL1	1.12	1.14	1.17	1.14	1.13	1.16	1.23	1.17
VCL2	1.19	1.23	1.26	1.23	1.17	1.25	1.29	1.24
Mean (A)	1.13	1.17	1.21		1.13	1.20	1.25	
LSD 5%	A: 0.03	B: 0.07	AB: 0.12		A: 0.04	B: 0.06	AB: 010	
	Stem diameter (cm)							
Control	1.48	1.44	1.39	1.44	1.44	1.41	1.35	1.40
NPK	1.68	1.63	1.55	1.62	1.66	1.59	1.51	1.59
VC1	1.57	1.52	1.45	1.51	1.51	1.46	1.43	1.47
VC2	1.63	1.61	1.51	1.58	1.59	1.55	1.47	1.54
VCL1	1.57	1.54	1.46	1.52	1.52	1.48	1.41	1.47
VCL2	1.64	1.59	1.53	1.59	1.61	1.56	1.49	1.55
Mean (A)	1.60	1.56	1.48		1.56	1.51	1.44	
LSD 5%	A: 0.03	B: 0.06	AB: 0.10		A:0.02	B: 0.05	AB: 0.09	
	Number of branches/plant							
Control	7.23	7.02	6.65	6.97	7.31	7.14	6.81	7.09
NPK	10.07	9.53	8.85	9.48	9.92	9.67	9.25	9.61
VC1	8.24	7.58	7.44	7.75	8.25	7.82	7.63	7.90
VC2	9.41	8.79	8.52	8.91	9.46	9.22	8.75	9.14
VCL1	8.52	7.56	7,48	8.04	8.55	8.05	7.52	8.04
VCL2	9.32	8.93	8.61	8.95	9.58	9.35	9.16	9.36
Mean (A)	8.80	8.24	8.01		8.85	8.54	8.19	
LSD 5%	A: 0.17	B:0.52	AB: 0.90		A: 0.23	B: 0.47	AB: 0.81	
	Herb dry weight (g/plant)							
Control	34.75	32.05	29.37	32.06	35.64	33.17	31.05	33.29
NPK	44.52	41.17	38.33	41.34	43.67	42.07	40.45	42.06
VC1	38.12	36.77	33.52	36.14	37.48	36.55	35.13	36.39
VC2	41.87	39.05	35.41	38.78	40.54	39.14	38.46	39.38
VCL1	39.22	37.82	33.67	36.90	37.95	37.67	36.50	37.37
VCL2	41.65	40.11	37.18	39.65	41.23	40.54	39.08	40.28
Mean (A)	40.02	37.83	34.58		39.42	38.19	36.78	
LSD 5%	A:2.13	B:3.25	AB: 5.62		A: 1.03	B: 2.84	AB: 4.91	

VC1= Vermicompost powder at 200 Kg/fed. VC2= Vermicompost powder at 300 Kg/fed.
VCL1= Vermicompost liquid at 100 liter/fed. VCL2= Vermicompost liquid at 150 liter/fed.

The interaction between plant density and NPK / vermicompost treatments was significant, in the two seasons, for each of plant height, stem diameter, branch number and herb dry weight/ plant as shown in Table (3).

The tallest plants in the two seasons were of the high density treatment those planted as 20 cm planting distance and fertilized with NPK or vermicompost at high level. The best overall results, for the another three vegetative growth traits were obtained due to supplying caraway plants with recommended dose of NPK, vermicompost liquid at 150 l/fed and vermicompost (VC2) at 300 Kg/fed, under (60 cm planting distance) then (40 cm plant distance). In general, no significant differences were detected between these three combined treatments. So, it is advisable, from the economical and environmental point of view, to fertilize caraway plants with VCL2 or VC2 under low or medium plant density.

II) Yield components parameters:

Number of umbels per caraway plant was sloping downward by increasing plant density in the two seasons as shown in table (4). Significant differences were obtained between the two planting densities treatment (low 60 cm & medium 40 cm planting distances), and the high one (20 cm planting distances) and without no significant between them. These results were identical in the two successive seasons Table (4). Numerically number of umbels/ plant was reduced by 9.5 and 35.4% in the first season and by 7 and 40.6% in the second season when 40 cm and 20 cm respectively were planting distances in comparison with that of 60 cm. The role of increasing number of total umbels /plant by decreasing plant density was insured by Bianco *et al.* (1994) on fennel.

Fruit yield per caraway plant sloping was by the gradual decrease in plant density in the two seasons as shown in Table (4). The differences were significant at 5% level between each two planting densities the reduction in fruit yield/plant due to planting distances of 40 and 20 (cm) in regard to that obtained from (60 cm) reached 20.7 and 49.8% in the first season and 15.2 and 53.3% in the second one, respectively. Such results were in great harmony with the finding of Munshi *et al*. (1990) on caraway and Hafez (1998) on *Nigella sativa*.

Table 4. Effect of plant density and fertilization treatments on yield components of caraway plants during two seasons 2019/2020 & 2020/2021.

Fertilization (B)	Plant Density (A) "Planting distance"							
	Planting distance 60 (cm)	Planting distance 40 (cm)	Planting distance 20 (cm)	Mean (B)	Planting distance 60 (cm)	Planting distance 40 (cm)	Planting distance 20 (cm)	Mean (B)
	First season 2019/ 2020				Second season 2020/ 2021			
	Number of umbels/ plant							
Control	24.36	20.23	14.76	19.78	23.55	19.66	13.57	18.93
NPK	26.18	24.34	17.25	22.59	27.08	26.42	16.67	23.39
VC1	24.85	22.69	16.09	21.21	24.92	22.53	14.12	20.52
VC2	26.13	24.15	16.95	22.41	27.15	25.56	16.25	22.99
VCL1	25.05	22.75	16.25	21.35	25.17	23.33	14.65	21.05
VCL2	25.92	23.88	17.13	22.31	26.55	26.18	16.44	23.06
Mean (A)	25.42	23.01	16.41		25.74	23.95	15.28	
LSD 5%		A: 3.12 B: 0.91	AB: 1.58			A: 4.33 B: 1.07	AB: 1.85	
	Fruit yield (g) / plant							
Control	22.61	17.53	11.41	17.18	23.35	19.24	11.06	17.88
NPK	33.34	27.44	16.85	25.88	34.26	28.38	15.75	26.13
VC1	26.97	19.87	13.12	19.99	25.33	23.81	12.42	20.52
VC2	31.57	25.65	15.93	24.39	32.70	26.87	14.71	24.76
VCL1	26.92	20.72	13.59	20.41	26.45	22.91	12.95	20.77
VCL2	32.75	26.85	16.53	25.37	33.75	27.87	15.25	25.62
Mean (A)	29.03	23.01	14.57		29.31	24.85	13.69	
LSD 5%		A: 4.33 B:2.45	AB: 4.24			A:3.73 B:2.05	AB: 3.55	
	Fruit yield (Kg) / fed.							
Control	518.81	613.90	798.85	643.85	535.90	643.76	767.16	648.94
NPK	767.92	957.93	1178.26	968.04	778.01	976.68	1101.08	951.92
VC1	619.58	698.43	920.21	746.07	581.93	796.83	871.18	749.98
VC2	725.53	900.06	1116.81	914.13	751.53	932.87	1003.16	895.85
VCL1	622.14	726.65	952.00	766.93	611.26	783.50	907.41	767.39
VCL2	753.84	942.17	1158.37	951.46	776.93	957.96	1068.87	934.59
Mean (A)	667.97	806.52	1020.75		672.59	848.60	953.14	
LSD 5%		A: 116.33 B: 59.21	AB: 102.55			A: 95.45 B: 63.72	AB: 110.36	

VC1= Vermicompost powder at 200 Kg/fed. VC2= Vermicompost powder at 300 Kg/fed.
VCL1= Vermicompost liquid at 100 liter/fed. VCL2= Vermicompost liquid at 150 liter/fed.

Fruit yield Kg/ feddan of caraway plants was gradually increased by the gradual increase in plant density in the two seasons as shown in Table (4). The differences between each two successive plant densities were significant and such results were identical in both seasons. The increase in fruit yield per feddan due to increasing planting density from 60 (cm) to 40 and 20 (cm) planting distances reached 20.8 and 52.8% respectively in the first season and 26.2 and 41.7% respectively in the second one as indicated in Table (4). Similar results were found on Caraway (Munshi *et al*, 1990) and anise (Randhawa *et al*, 1992).

Concerning fertilization treatments, all used treatments were significantly effective in producing higher number of umbels/ plant and heavier fruit yield /plant and per feddan than that of unfertilized plants in the two seasons. Among the five examined treatments, recommended dose of NPK followed by vermicompost liquid (VCL2) at 150 liter/fed then vermicompost (VC2) at 300 Kg/fed treatments gave the highest number of umbels/ plant and heaviest fruit yield per plant and per fed while VC1 at 200 kg/fed and VCL1 at 100 liter/fed gave the lowest values. The increase in fruit yield per fed due to these three treatments (NPK, VCL2 and VC2), respectively came to 50.4, 47.8 and 42% in the first season and 46.7, 44 and 38.1% in the second season. No significant differences were existed, in both seasons, for fruit yield per plant and per fed among such three superior treatments as obviously illustrated in Table (4).

In agreement with these results, concerning organic fertilization, were the findings of Tanious (2008) on fennel; Seghatoleslami (2013) on cumin and Abul-Soud *et al*. (2014) on *Pisum sativum*. While, Abd El- Naeem (2008) on caraway insured the efficiency of mineral NPK fertilizers in augmenting fruit yield. Phosphorus, which has been referred to as the "key to life," is necessary for cell division, the growth of mesenchymal tissue, and the transformation of carbohydrates due to the numerous phosphorylation reactions and the energy-rich phosphate bond (Lambers *et al*, 2000).

The superiority of nutrient contents in plants resulting from vermicompost extract treatment on compost extract might be due to the fact that compost contains higher ammonium nitrogen, while the vermicompost is higher in nitrate nitrogen content, which is the more available form for plant absorption. In addition, the nutrients are released from vermicompost during short time compared to vermicompost. These results are in harmony with those obtained by Bulalin *et al*. (2015) and Kovacik *et al*. (2015).

Table (4) shows that the interaction between factor A (plant density) and factor B (fertilization), for number of umbels/ plant and fruit yield per plant and per fed, was significant in both seasons. The highest values were supplied with high plant density in combination with NPK. However, this superior treatment was statistically equal to that one received high or medium in combination with the VCL2 or VC2 fertilization treatments. the best results in the two experimental seasons of fruit caraway yield/feddan were obtained due to supplying caraway plants with NPK or the high dose of vermicompost liquid/ powder under high density at 20 (cm) planting distance.

III) Volatile oil productivity:

Oil percentage and oil yield per plant were sloping downward by the gradual increase in plant density. These results were identical in both first and second seasons. Moreover, the differences between each two successive plant density treatments, in both seasons for oil yield/ plant proved to be significant as illustrated in Table (5). Numerically, oil yield/plant was decreased by 22.6 and 55.9% respectively in the first season and 15.3 and 58.8%, respectively in the second

season due to increasing plant density from 60 (cm) to 40 and 20 (cm) planting distances, respectively. Many authors came to the conclusion that the increase in oil yield/plant is parallel to the reduction plant in density such as El-Tantawy *et al*. (1992) on fennel and Sukhadia *et al*. (1986) on coriander.

It was observed that the essential oil yield/feddan was affected in the opposite direction from that exhibited by oil yield/plant as a result of different plant density treatments. That means that essential caraway oil yield/feddan was gradually increased parallel to the increase in plant density. Moreover, the differences between each respective treatment were significant in the two experimental seasons. The yield of oil/feddan was augmented by 16.6 and 30.2% respectively in the first season as a result of increasing plant density from 60 (cm) to 40 and 20 (cm) planting distances. The corresponding increases in the second season reached 22.5 and 31.9%, respectively as illustrated in Table (5). In harmony with the prementioned results were the findings of Aiello and Bezzi (1997) on fennel, Hafez (1998) on *Nigella sativa* and Abbas (2014) on sweet basil.

Table 5. Effect of plant density and fertilization treatments on volatile oil productivity of caraway plants during two seasons 2019/2020 & 2020/2021.

Fertilization (B)	Plant Density (A) "Planting distance"							
	Planting distance 60 (cm)	Planting distance 40 (cm)	Planting distance 20 (cm)	Mean (B)	Planting distance 60 (cm)	Planting distance 40 (cm)	Planting distance 20 (cm)	Mean (B)
	First season 2019/ 2020				Second season 2020/ 2021			
	Oil percentage							
Control	2.82	2.61	2.34	2.59	2.59	2.49	2.24	2.44
NPK	3.25	3.12	2.65	3.01	3.32	3.19	2.83	3.11
VC1	2.87	2.75	2.48	2.70	2.93	2.81	2.53	2.75
VC2	3.08	2.83	2.59	2.83	3.26	3.03	2.73	3.01
VCL1	2.93	2.74	2.51	2.73	3.08	2.88	2.64	2.86
VCL2	2.98	3.01	2.63	2.87	3.16	3.26	2.79	3.07
Mean (A)	2.99	2.84	2.53		3.06	2.94	2.63	
LSD 5%		A: 0.18 B:0.09	AB: 0.16			A: 0.21 B:0.13	AB: 0.23	
	Oil yield (ml)/ plant							
Control	0.62	0.47	0.28	0.46	0.59	0.49	0.24	0.44
NPK	0.99	0.83	0.43	0.75	0.98	0.91	0.40	0.76
VC1	0.75	0.53	0.32	0.53	0.75	0.64	0.30	0.57
VC2	0.93	0.72	0.41	0.69	0.96	0.78	0.43	0.72
VCL1	0.79	0.55	0.33	0.56	0.83	0.63	0.33	0.60
VCL2	0.95	0.78	0.42	0.72	0.97	0.86	0.41	0.75
Mean (A)	0.84	0.65	0.37		0.85	0.72	0.35	
LSD 5%		A:0.15 B:0.06	AB: 0.10			A: 0.17 B: 0.08	AB: 0.14	
	Oil yield (l)/ feddan							
Control	14.50	15.45	18.89	16.28	13.68	16.57	17.21	15.13
NPK	23.22	29.16	30.37	27.58	22.98	28.44	31.95	25.71
VC1	17.61	18.61	22.07	19.43	17.12	21.17	22.59	19.14
VC2	21.90	26.72	28.87	25.83	22.51	27.08	29.52	24.80
VCL1	17.94	19.34	23.14	20.14	18.99	23.00	24.29	20.99
VCL2	22.20	27.53	29.49	26.41	22.75	28.13	30.07	25.44
Mean (A)	19.56	22.80	25.47		19.67	24.06	25.94	
LSD 5%		A: 2.07 B: 1.92	AB: 3.32			A: 1.77 B: 1.55	AB: 2.68	

VC1= Vermicompost powder at 200 Kg/fed. VC2= Vermicompost powder at 300 Kg/fed.
VCL1= Vermicompost liquid at 100 liter/fed. VCL2= Vermicompost liquid at 150 liter/fed.

Regarding fertilization treatments, obtained data in Table (5) show that the five mineral and organic fertilization treatments, namely, NPK, vermicompost (VC1) at 200 Kg/fed, vermicompost (VC2) at 300 Kg/fed, vermicompost liquid (VCL1) at 100 liter/fed and vermicompost liquid (VCL2) at 150 liter/fed), caused noticeable and great increase in essential oil percent and yield per plant and per fed, in the two seasons, over those of control unfertilized plants. Such increase was significant due to all these five treatments for the essential oil yield per plant and per fed. Among the five examined vermicompost and NPK treatments, each of the three essential oil parameters, was gradually increased, in ascending order, due to VC1, VCL1, VC2, VCL2 and NPK. These results were almost identical in the two seasons as illustrated in Table (5).

The increase in essential oil yield per feddan due to the use of the previously mentioned five treatments, in comparison with control treatment, reached 19.3, 23.7, 58.7, 62.2 and 69.4% in the first season; and 26.5, 38.7, 63.9, 68.1 and 69.9% respectively in the second season. The role of organic fertilization in augmenting essential oil parameters was reported by Abd El-Naeem (2008) on caraway and Abdalla (2009) on coriander. While that NPK was insured by Al- Shareif (2012) on *Nigilla sativa* and Badran *et al.* (2013) on coriander.

Potassium is necessary for growth and elongation likely because of its role as an osmoticum and may interact synergistically with IAA; also, it encourages CO2 as a simulation and the translocation of carbohydrates from the leaves to storage tissues. (Mengel and Kirkby 1987). This corresponds with the recommendation for applying vermicompost for enhancing plant growth productivity and quality by increasing the amount of available nutrients (nitrates, exchangeable P, K, Ca and Mg) Arancon *et al*. (2004) and Senthilkumar *et al*. (2004). Additionally, this enhanced the physicochemical characteristics of the soil, boosted enzymatic activity, increased microbial diversity and activity, nutritive elements, and plant development regulators. Arancon *et al*. (2004) and Eudoxie *et al*. (2017).

The interaction between different plant densities and fertilization treatments was significant, in both seasons, for the three caraway essential oil parameters, percent and yield per plant and per fed, as clearly shown in Table (5). The highest value for the oil percentage and fruit oil yield/plant parameters was obtained when caraway plants were fertilized with the recommended dose of NPK or the high concentration of vermicompost liquid/ powder under low density. On the other hand, the best results in the two experimental seasons of oil yield/feddan were obtained due to supplying caraway plants with a recommended dose of NPK or the high concentration of

vermicompost liquid/ powder under high density at 20 (cm) planting distance. However, from the practical, economical and environmental point of view, no significant differences were existed, in both seasons for the three essential oil parameters, between solely NPK traditional treatment and that of the high dose of vermicompost (liquid or powder) treatment as clearly indicated in Table (5).

IV) Nitrogen, Phosphorus and Potassium %:

Nitrogen and potassium percentage of caraway plants were gradually decreased by the gradual increase in plant density as shown in Table (6) for both experimental seasons. The differences were statistically significant between each two successive plant density treatments. While, the phosphorus percentage in the herb was not effected by different plant density treatments. In the meantime a slight increase in phosphorus percentage by increasing the planting distances from 20 up to 60 (cm) could be observed. In close agreement with these results concerning NPK were those revealed by Ahmed (1997) on *Nigella sativa*.

The herb N, P and K percent were significantly increased, in both seasons, due to majority of NPK and vermicompost (powder or liquid) fertilization treatments as indicated in Table (6). The highest values for the three nutrients were obtained, in descending order, due to NPK, VCL2, VC2, VCL1 and VC1. It is worth to mention that the differences between the first three previously mentioned treatments, for N, P and K % in both seasons, did not reach the level of significantly as shown in Table (6). The role of organic fertilization in promoting N, P and K % was given by Abdalla (2009) on coriander and Hassan *et al*. (2010) on dill. While that of mineral NPK was revealed by Abd El- Naeem (2008) on caraway and Tanious (2008) on fennel. Vermicompost contains a well-balanced composition of nutrients. The physical conditions of the soil, the development of soil microorganisms, and the solubility of reserved mineral substances may have been improved by humic acid and vermicompost components, which in turn may have increased the availability and uptake of plant nutrients during the plant's growth phase. Chatterjee *et al*. (2006) and Alkobaisy and Naeem (2021).

The interaction between three planting distances and fertilization treatments was significant, in the both seasons, for the three caraway N, P and K percentages, as clearly shown in Table (6). The highest value for the NPK %, were obtained when caraway plants were fertilized with the mineral NPK or the major dose of VCL or VC under 60 (cm) planting distance. However, no significant differences were existed, in both seasons for the three NPK%, between solely NPK traditional treatment and that of the high dose of vermicompost (liquid or powder) treatment.

Table 6. Effect of plant density and fertilization treatments on N, P and K percentages of caraway plants during two seasons 2019/2020 & 2020/2021.

Fertilization (B)	Plant Density (A) "Planting distance"							
	Planting distance 60 (cm)	Planting distance 40 (cm)	Planting distance 20 (cm)	Mean (B)	Planting distance 60 (cm)	Planting distance 40 (cm)	Planting distance 20 (cm)	Mean (B)
	First season 2019/ 2020				Second season 2020/ 2021			
	Nitrogen percentage (N %)							
Control	2.137	2.117	2.055	2.103	2.136	2.039	1.979	2.051
NPK	2.425	2.416	2.375	2.405	2.336	2.327	2.288	2.317
VC1	2.252	2.174	2.132	2.186	2.169	2.094	2.054	2.106
VC2	2.394	2.367	2.355	2.372	2.306	2.280	2.268	2.285
VCL1	2.261	2.185	2.129	2.192	2.178	2.105	2.051	2.111
VCL2	2.410	2.388	2.346	2.381	2.321	2.300	2.260	2.294
Mean (A)	2.313	2.275	2.232		2.241	2.191	2.150	
LSD 5%		A: 0.052 B: 0.066	AB: 0.114			A: 0.037 B: 0.046	AB: 0.080	
	Phosphorus percentage (P %)							
Control	0.295	0.288	0.282	0.288	0.284	0.277	0.272	0.278
NPK	0.377	0.365	0.358	0.367	0.363	0.352	0.345	0.353
VC1	0.335	0.327	0.311	0.324	0.323	0.315	0.300	0.312
VC2	0.368	0.352	0.338	0.353	0.354	0.339	0.326	0.340
VCL1	0.344	0.331	0.317	0.331	0.331	0.319	0.305	0.318
VCL2	0.372	0.359	0.346	0.359	0.358	0.346	0.333	0.346
Mean (A)	0.349	0.337	0.325		0.336	0.325	0.313	
LSD 5%		A: 0.009 B: 0.028	AB: 0.048			A: 0.007 B: 0.025	AB: 0.043	
	Potassium percentage (K %)							
Control	1.198	1.124	1.081	1.134	1.244	1.167	1.122	1.178
NPK	1.757	1.690	1.574	1.674	1.824	1.755	1.634	1.738
VC1	1.455	1.430	1.297	1.394	1.511	1.485	1.347	1.448
VC2	1.671	1.562	1.495	1.576	1.735	1.622	1.552	1.636
VCL1	1.488	1.459	1.353	1.434	1.545	1.515	1.405	1.488
VCL2	1.697	1.530	1.553	1.593	1.762	1.588	1.612	1.654
Mean (A)	1.544	1.466	1.392		1.604	1.522	1.445	
LSD 5%		A: 0.062 B: 0.105	AB: 0.182			A: 0.069 B: 0.114	AB: 0.197	

VC1= Vermicompost powder at 200 Kg/fed. VC2= Vermicompost powder at 300 Kg/fed.
VCL1= Vermicompost liquid at 100 liter/fed. VCL2= Vermicompost liquid at 150 liter/fed.

CONCLUSION

Environmentally, it could be concluded that to maximize the fruit and essential oil yield per feddan, supplying caraway plants with the high concentration of vermicompost powder or liquid (VC at 300 Kg/fed or VCL at 150 liter/fed) with planting distances of 20 (cm) between each hill, under the environmental conditions of the same study.

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تأثير الكثافة النباتية ومعاملات التسميد على نمو وإنتاجية نباتات الكراوية

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الملخص

تم اجراء هذا البحث خلال موسمي 2020/2019 و 2021/2020م في المزرعة التجريبية بمحطة بحوث البساتين بسدس، بني سويف. وتهدف إلى معرفة مدى استجابة نباتات الكراوية لمعاملات الكثافة النباتية وبعض معاملات التسميد من حيث النمو الخضري (طول النبات - سمك الساق - عدد الأفرع - وزن العشب الجاف) وكذلك معاملات المحصول (عدد النورات ومحصول الثمار للنبات والفدان) ونسبة الزيت الطيار ومحصول النبات والفدان و NPK %. اشتملت الكثافة النباتية على ثلاث معاملات وتتمثل في مسافة الزراعة (60 - 40 - 20 سم) بين الجور، بينما تضمنت معاملات التسميد خمسة معدلات لكل من NPK ومسحوق كمبوست الديدان بمعدل 200 و300 كجم / فدان و سائل كمبوست الديدان بمعدل 100 و 150 لتر / فدان . وذلك باستخدام تصميم القطع المنشقة مرة واحدة. تم الحصول على أفضل محصول للثمار والزيت الطيارللفدان عند زراعة نباتات الكراوية بكثافة نباتية مرتفعة (20 سم). فيما يتعلق بمعاملات التسميد، تم زيادة جميع صفات النمو ومحصول الثمار والزيت بشكل كبير بسبب التسميد المعدني NPK يليها الجرعة المرتفعة من سائل او مسحوق كمبوست الديدان ، بينما أعطت الجرعة الاقل من مسحوق وسائل كمبوست الديدان أقل النتائج .فيما يتعلق بمعاملات التداخل، تم الحصول على أعلى قيم محصول الثمار والزيت عن طريق تسميد نباتات الكراوية بالتسميد المعدني والزراعة على مسافات (20سم) بين الجور. ولايوجد فروق معنوية بين NPK والمعدل العالي من كمبوست الديدان، لذا يُنصح من الناحية الاقتصادية والبيئية، بتسميد نباتات الكراوية بكمبوست الديدان السائل بمعدل 150 لترًا / فدانًا أو مسحوق كمبوست الديدان بمعدل 300 كجم / فدان لتحسين إنتاجية الثمار والزيت الطيار لنباتات الكراوية.