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CONTENTS

1 INTRODUCTION

Egypt covers an area of about one hundred million hectares. However, the only cultivated regions in Egypt are the narrow Nile river valley (upper Egypt), the Nile delta in the north (lower Egypt), the shore of the Suez canal in the east and newly reclaimed land (Abdel-Fattah, 1993). This amounts to 3.6 million hectares cultivated land (Abdel-Fattah, 1993). From the total land owners 94 % held about 35.5 % of the land (area less than 2 ha) while only 0.8 % of the owners held the remaining 19.7 % (area more than 100 ha) (Gadalla, 1962). Because more than 96 % of the total land owners held 50 % of the land, most of the farms in Egypt are small farms (less than 10 ha) (El-Kady and Hanigan, 1993 and Abdel Rahman et al. 1995).

Generally the owners of small farms produce far more yield per unit area than owners of larger farms do (Carter, 1984). In addition they achieve higher and more dependable production from their land than it is the case on larger farms operating similar environments (Cornia, 1985). Labour intensive practices such as manuring, limited tillage, ridging, terracing, composting organic matter and recycling plant products into the productive process, enhance soil conservation and fertility (Strange, 1988). Large farmers tend to plant mono-cultures because they are the simplest to manage with heavy machinery (Netting, 1993). Small farmers on the other hand, especially in most African countries, are much more likely to plant crop mixtures and practice inter-cropping, where otherwise on the empty niche space weeds would grow (Gadalla, 1962 and Netting, 1993). They also tend to combine or rotate crops and livestock, with manure serving to replenish soil fertility (Netting, 1993).

In Egypt, the smallest farms have more than ten times greater monetary output per hectare than larger farms (Barret, 1993). This mainly is due to the fact that small farms tend to specialise in high value crops like vegetables, flowers plants, medicinal and aromatic plants, but it also reflects relatively more labour and inputs applied per unit area and the use of more diverse farming systems (Strange, 1988). While large farmers very often use monocultures and one or at the most two rotations per year, small farmers are more likely to intercrop various crops on the same field, plant multiple times during the year, integrate crops, livestock and even aqua-culture and thus making much more intensive use of space and time. Large farmers and land owners tend to leave much of their land idle, while small farmers tend to use their entire parcel (Barret, 1993).

Medicinal and aromatic plants are important economic products which represent significant sources of economic revenue and foreign exchange and are among the most important agricultural export products (Watt and Breyer, 1962). Egypt's soil is world-famous for growing high-quality medicinal and aromatic plants which are more than 150 in number. Most of these crops are exported abroad. Total exports of this crop hit more than $ 50 million a year. These are grown on 15000 hectares. As a primarily export-oriented product, these plants are subjected to a thorough system of production management. Medicinal and aromatic plants have the potential of boosting Egyptian exports of high-quality, added-value crops such as chamomile, fennel, peppermint etc.. The relative export edge of such crops lie in the availability of products as well as a growing world demand. Other relative advantages of this business include that only scanty areas are required for growing these plants and the need of intensive labour and low water requirements (Egypt Magazine, 2000). Recently, an increasing interest in the cultivation and production of medicinal plants has been noticed in Egypt in order to cover the increasing demand of the local industries as well as for export purposes (Belal, 1995). Many medicinal and aromatic plants need intensive labour for their cultivation, weed control, cutting, manual harvesting, collection of flower and seeds, drying, processing, seeds and sepals separation. Small farms tend to specialise in high value crops like flowers, medicinal and aromatic plants, it also reflects relatively more labour and inputs applied per unit area, and the use of more diverse farming systems (Abdel-Salam, 1991). Most of medicinal and aromatic plants are cash crops, they can increase the farm income and decrease unemployed population which is desirable in Egypt (Abdel Rahman et al. 1995) like in most African countries.

Cultivation of medicinal and aromatic plants in the small farms thus can decrease migration into towns (El Kadi, 1988) and the small farmer rural economy provide the basis for strong national economic development (Netting, 1993).

Since intensive use of farm land might go along with mismanagement respectively over management leading to loss of soil fertility and together with these reduction of physical and microbiological soil parameters. Therefore and because there are some restrictions of growing medicinal plants like for instance avoiding the use of herbicides, fungicides and pesticides it seems reasonable to practice organic farming.

The idea of organic farming goes back to Rudolph Steiner (1924) and has been discussed more and more in recent years. The term "organic farming" now is well defined by the EU regulations 2092/91 (1991) and has been adopted by the FAO and the WHO in 1999 (Codex Alimentarius, 2001).

Organic farming involves holistic production management systems (for crops and livestock) emphasizing the use of management practices in preference to the use of off-farm inputs. This is accomplished by using, where possible, cultural, biological and mechanical methods in preference to synthetic materials. The EU regulations specify that an organic production system is designed to:

- enhance biological diversity within the whole system;
- increase soil biological activity;
- maintain long-term soil fertility;
- recycle wastes of plant and animal origin in order to return nutrients to the land, thus minimising the use of non-renewable resources;
- rely on renewable resources in locally organized agricultural systems;
- promote the healthy use of soil, water and air as well as minimise all forms of pollution thereto that may result from agricultural practices;
- handle agricultural products with emphasis on careful processing methods in order to maintain the organic integrity and vital qualities of the product at all stages;
- become established on any existing farm through a period of conversion, the appropriate length of which is determined by site-specific factors such as the history of the land, and type of crops and livestock to be produced.

To increase the crops quality especially medicinal and aromatic plants, organic fertilization is more acceptable than chemical fertilizers and organic farming is a quality standard to be matched good by small farmers in Egypt (Abou El-Fadl et al. 1990)

Since fennel (*Foeniculum vulgare* Mill.) is one of the most important medicinal plants grown within the Mediterranean region, in Europe and in Egypt, it's export value amounts to 10 million US $ from Egypt, investigations to improve the possibilities of growing fennel also on newly reclaimed land within Egypt have been done. The Egyptian government in collaboration with the WHO seeks to protect these plants that serve as sources for pharmaceutical compounds and who might increase the export of these plants from Egypt to all over the world (Egypt Magazine, 2000).

Fennel (*Foeniculum vulgare* Mill.) also called *Foeniculum officinale* All., *Foeniculum capillaceum* Gilib., *Meum foeniculum* Spreng. or *Anethum foeniculum* L. belongs to the family of the *Umbelliferae* (*Apiaceae*). The generic name derives from the Latin *foenum*, which means hay, referring to the foliar structure. The plant is biennial growing to a height of about 2 m with a large spindle shaped root. The leaves have thick, amplexicaul, fleshy sheath which is edible (Chiej, 1984). Besides the use as a vegetable the pharmacopoeial use concentrates on the fruits and the important ingredient is the oil. Therefore the pharmacopoeial name is *Foeniculi aetheroleum*. According to the composition of the fruits oil the pharmacopoeia also differentiates between sweet fennel (*Foeniculi dulcis fructus*) with about 2 % oil content with about 80 % anethole and bitter fennel (*Foeniculi amari fructus*) with about 4 % oil content, 60% anethole and about 15 % fenchone (Wagner, 1999). The fennel seeds are tiny and yellowish green, resemble cumin seeds except that when bruised they explode with licorice fragrance reminiscent of anise. Botanically the seeds are defined as fruits (Bhati et al. 1988 and Buntain and Chung, 1994).

Fig. (1-1): Fennel (*Foeniculum vulgare* Mill.)

Fennel is used in folk medicine as a stimulant, diuretic, carminative and sedative (Charles et al. 1993) and galactagogic, emmenagogic, expectorant and antispasmodic (Chiej, 1984). Fennel fruits are used to treat diseases like cholera bile disturbances, nervous disorder, constipation, dysentery and diarrhoea (Leung and Foster, 1996). It is also used for control of diseases affecting chest, lungs spleen, kidneys and in colic pains (Bown, 1995). Fennel is also considered as a spice due to terpenic compounds isolated from its fruits volatile oil (Masada, 1967). Also fennel fruits are widely used in the preparation of various dishes like soups, sauces, pastries, confectioneries, pickles and meat dishes etc. (Bhati et al. 1988). The leaf stalks and the tender shoots are also used in salads. Fennel is used in cooking for liqueurs (Bhati et al. 1988). The essential oil of fennel is used to flavor different food preparations and in perfumery industries. The oil, which contains anethole, i.e., 1-methoxy-4-(1-propenyl) benzene, fenchone, i.e., (+) trimethyl (2,2,1) bicycloheptan-2-one, is of paramount importance in pharmaceutical and other industries as well as in confectionery (Abdallah et al. 1978). Its modern therapeutic uses in Germany and the United States stem from traditional Greek medicine as practiced by Hypocrites and later by Discorides (Leung and Foster, 1996). It is still widely used in traditional Arabian medicine as diuretic appetiser and digestive (Kranick, 1994). Fennel's therapeutic uses have been introduced and integrated into many other systems of traditional medicine, including Ayurvedic, Chinese and Japanese Kampo (Wichtl and Bisset, 1994). The present Ayurvedic pharmacopoeia recommends it in dried fruit or fluid extract form, for flatulent dyspepsia, anorexia, and flatulent colic in children (Karnick, 1994). In Germany, fennel fruits are licensed as a standard medicinal tea for dyspepsia (Arslan et al. 1989). It is also used in cough syrups and honeys (antitussives and expectorants), and stomach and bowel remedies, especially in paediatrics as aqueous infusion, juice and syrup (Wichtel and Bisset, 1994). In the United States, it is also used as a component of galactagogue preparations (Leung and Foster, 1996). Fennel oil is used as an expectorant component of cough remedies, and also as carminative component of stomach and bowel remedies in dosage forms including honey and syrup (Khan et al. 1992 and Marotti and Piccaglia, 1992).

Because of fennel's use in so many ways there might be world wide a growing market like for all medicinal and aromatic plants. Also, because there is a change from traditional medicinal practice using mostly chemicals to homeopathic kind of medicine using mostly herbal medicine, in Egypt large areas of newly reclaimed and desert land have been cultivated with medicinal and aromatic plants during the last few years (Belal, 1995).

The intensive farming on Nile valley soils in Egypt and agriculture practices have forced the farmers to use more fertilizers to get the high benefit. The intensive use of manufactured nitrogen fertilizers increased the crops productivity but with low quality which is not acceptable for export (Lain et al. 1996 and Wang et al. 1996). Very little information is available on the specific requirements of fennel fertilization on newly reclaimed land and in the intensively cultivated Nile valley in Egypt. One also has to take into account that the essential oil content and the components of fennel oil are qualitatively different between not only the different varieties of fennel: *vulgare* (bitter), *dulce* (sweet) and *azoricum* (florance), (Marotti et al. 1994) but also between the different continental cultivars of bitter fennel (Masada, 1967, Massoud, 1992 and Braun and Franz, 1999). Therefore, in this study the Egyptian cultivar of bitter fennel has only been selected as a test plant.

The key objectives of this work were

1- To investigate the performance of fennel growth with fertilization sources accepted in organic farming and compare it with common fertilization practices
2- To investigate if *Azotobacter* inoculation is a suitable source to improve the nitrogen supply of fennel on Egyptian soils
3- To investigate if mixing of elemental sulphur with rockphosphate is suitable to increase P availability to fennel plants and increase the yield and quality of fennel under the Egyptian conditions
4- To investigate the effect of different fertilization practices on the yield and essential oil quality of fennel with the general recommendation for improving the production of fennel according to high quality standards on small farms

2 MATERIAL AND METHODS

2.1 Sites and soils

Field experiments were carried out in the newly reclaimed lands and in the old cultivated lands of the Nile valley during two successive seasons (1998/1999 and 1999/2000). The first experiment was performed at the Sekem company farm in Heykastep (15 km east of Cairo). The major system of irrigation in this farm was drip irrigation system using Nile water. The second experiment was performed at the experimental farm of the Cultivation and Production of Medicinal and Aromatic Plants Department, National Research Centre, at Giza as a comparison site for the old cultivated lands in the Nile valley, which was irrigated by Nile water using a flood irrigation method. The chemical and physical analysis of the soils are shown in tables 1 and 2. The site of the two locations on the Egyptian map are given in Figure (2-1).

Table 1: Chemical and physical characteristics of the soils of the tested sites

Soil types (Location)	Depth (cm)	O. M. (%)	$CaCO_3$ (%)	EC (ds m^{-1})	(m eq/100 g soil) water extract (1:5)						
					Na^+	K^+	Ca^{++}	Mg^{++}	HCO_3^-	Cl^-	SO_4^{--}
Sandy soil (Sekem farm)	0-30	0.70	3.04	1.06	0.40	0.24	0.92	0.70	0.24	0.70	1.23
	30-60	0.34	2.72	0.28	0.14	0.12	0.36	0.24	0.24	0.40	0.22
Clay loam soil (Giza farm)	0-30	1.74	3.15	0.90	7.02	0.38	1.60	0.75	0.55	0.75	6.98
	30-60	1.40	3.60	0.60	3.00	0.23	1.25	0.75	0.75	0.75	0.97

Table 2: Initial fertility status of the tested soils from the experimental sites

Location	pH	Total Nitrogen (mg kg^{-1})	Total carbon (%)	CAL Extract		DTPA Extract			
				Avail. P (mg kg^{-1})	Avail. K (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})
Sekem farm (98/99)	7.9	338	1.00	5.6	11	3.4	9.2	1.9	1.8
Sekem farm (99/00)	7.8	1406	1.88	21.6	24	6.0	20.0	1.5	9.4
Nile valley (98/99)	8.0	1358	2.31	6.2	22	7.7	14.0	4.1	2.1
Nile valley (99/00)	8.1	1628	2.10	6.4	19	8.1	15.0	3.6	2.0

Fig. (2-1): Location map of studied farms in Egypt

2.2 Experimental Design

The experimental design was a split-split plot with four replicates. The sub-sub plots area were (3 x 4 m) on the experimental farm in Giza (Nile valley) and one row (0.70 m. x 10 m) on the Sekem farm. The two potassium sources: feldspar and potassium sulphate (control) were arranged in the main plots and phosphorus sources: rockphosphate, rockphosphate mixed with elemental sulphur and calcium super phosphate were arranged in the sub-plot while the different nitrogen sources: compost, chicken manure, compost/*Azotobacter* and ammonium nitrate occupied the sub sub-plots.

Foeniculum vulgare Mill. seeds were obtained from Sekem Company, Egypt. Sowing was done in the first season on October 20th and 22nd (1998) and in the second season on October 21st and 22nd (1999) at the Giza and the Sekem farm respectively. Fennel seeds were manually sown in rows (70 cm between rows). Germination was practically completed after 12 days from sowing. After 30 days plants were thinned to two plants per hill at 20 cm interval.

2.3 Treatments

In the context of this study organic fertilizers means fertilizers in accordance with the European Union (EU) standards for "organic farming" and the control are manufactured fertilizers. The different sources of the plant nutrients are summarized in table 3.

Table 3: Organic and inorganic sources of the plant macronutrients

Nutrient	Control	Organic sources
N	Ammonium nitrate	Compost, chicken manure and compost/Azotobacter
P	Superphosphate	Rock-P and rock-P/S
K	Potassium sulphate	Feldspar

Nitrogen Fertilization

Nitrogen was applied at the rate of 250 kg ha^{-1} **N** from the following nitrogen sources;

1. Compost alone
2. Chicken manure
3. Compost/*Azotobacter*
4. Ammonium nitrate (control)

Compost and chicken manure were added in two portions, the first one during the preparation of soil before sowing and the second portion was added three months after sowing date in both sandy and clay loam soils. The physical and chemical analyses of compost and chicken manure are shown in table 4.

Because most of Egyptian soils are poor in organic matter, fennel seeds had been inoculated with *Azotobacter chroococum* through seed dressing directly before sowing plus 20 and 45 days thereafter the soil has been inoculated with the same bacteria culture on those plots which had been treated with compost according to Abd-EI-Malek (1971).

Control: Ammonium nitrate (33.5 % N) was added in two portions. The first portion (half) after germination and the second three month after the first one (at the beginning of flowering stage).

Table 4: Some physical and chemical analysis of compost and chicken manure

Character	Chicken manure	Compost
Weight of one m^3 (kg).	493	521
Wet. (%)	30	35
Total N (%)	1.6	1.5
O. M. (%)	52	47
Total carbon (%)	30	34
C/N ratio	19	23
Total phosphorus (%)	2.9	0.5
Total potassium (%)	0.8	2.4

Phosphorus fertilization

Phosphorus fertilizer was added at the rate of 40 kg **P** per hectare during the preparation of soil (before sowing) from the following phosphorus sources:

1- Rockphosphate alone (rock-P)
2- Rockphosphate mixed with 120 kg elemental sulphur per hectare (rock-P/S)
3- Calcium superphosphate (super-P) as control

The chemical analyses of the rockphosphate is given in table 5

Potassium fertilization

Potassium fertilizer was applied at the rate of 50 kg **K** per hectare during the preparation of the soils (before sowing) in form of potassium feldspar and potassium sulphate (as control). The chemical analyses of the feldspar is given in table 5.

Table 5: Some chemical analysis of feldspar and rockphosphate

Assay	Rockphosphate	Feldspar
Total P (g kg^{-1})	110	0.3
K_2O (%)	Trace	10.5
SiO_2 (%)	9.0	66
Al_2O_3 (%)	0.9	19
Fe_2O_3 (%)	1.2	0.3
Total Cu (mg kg^{-1})	19	7.0
Total Zn (mg kg^{-1})	127	26
Total Fe (g kg^{-1})	10	6.4
Total Mn (mg kg^{-1})	284	152

2.4 Sampling and preparation

To interpret the effects of the different treatments on the yield of fennel fruits and essential oil, plant height, number of branches per plant and dry weight of fennel were investigated during the different growth stages. Samples were taken at random from the rows for growth studies. Plants were chosen from every sub-plot of all replications of every different treatment. Always three samples were taken after 90 days and 160 days after sowing and at the final harvesting date which represented the vegetative, flowering and maturity stages, respectively.

For the interpretation of the growth characteristics the following parameters have been taken into account:

● Plant height (cm)

● Number of branches per plant

● Plant dry weight

Fresh plants were weighed then dried at 60 °C till constant weight was obtained and dry weight (g $plant^{-1}$) was calculated.

● Fruit yield (g $plant^{-1}$)

At the end of the experiment, the plants were harvested and the yield of fruits were recorded (kg ha^{-1}).

Soil samples were taken three weeks after the addition of the second portion of fertilization (first sample) and after fennel harvest (second sample). From each treatment four replicates were mixed together in both sandy and clay loam soils in both seasons and were kept for soil analysis. All soil samples were air dried, grounded and sieved to pass a 2-mm mesh sieve; the sieved samples were stored for analysis as indicated in table 6.

2.5 Chemical analysis

Plant and soil analysis

Plant analyses for mineral composition have been done in the vegetative stage, because this reflects best the supply status with mineral elements (Bergmann, 1983). The plant samples were oven dried at 70 C^o for 72 hours and were analysed for their macro- and micronutrient content as indicated in table 6.

Essential oil extraction

Essential oil was isolated using a Clevenger-type apparatus according to Marotti and Piccaglia (1992).

- 100 g of fresh fennel herb have been distilled for three hours in one liter water at the vegetative stage.
- 100 g of fresh fennel herb and flowers have been distilled for three hours in one liter water at flowering stage.
- 25 g of the fennel fruits have been distilled for three hours in 500 ml water.

- The percentage of essential oil per dry weight has been calculated thereafter.

  Essential oil yield (l ha^{-1}) was calculated by multiplying essential oil percentage and fruit yield (kg ha^{-1}).

Table 6: Analytical methods for plant and soil analysis

Parameters	Methods
Soil samples	
Soil pH	Potentiometery in 1:5 (soil:water) suspension according to (Jackson, 1973)
Available phosphorus	Calcium ammonium lactate extract (Schüller, 1969)
Available potassium	Calcium ammonium lactate extract, flame photometer
DTPA extractable Fe, Mn, Zn and Cu	DTPA-extractable Fe, Mn, Zn and Cu -soils were extracted using DTPA (diethylenetriaminepentaacetate) according to Lindsay and Norvell (1978), elements analysed by ICP-AES
Plant samples	
Total N	Kjeldahl method
Total P	Dry ash, spectrophotometer
Total Ca	Dry ash, flame photometer
Total K	Dry ash, flame photometer
Total Mg, Fe, Mn, Zn and Cu	0.5 g of the ground plant material was dry ashed at 470 °C in a crucible overnight, the ash dissolved with 10 ml conc. HCl and diluted up to 50 ml with distilled water in a measuring flask. Elements were determined in the clear filtrate by means of a flame (air–acetylene) atomic absorption spectrometer (AAS, Unicam Solar 929). The tool was calibrated with the appropriate standard solution.

Essential oil analysis

To study the effect of different fertilization treatments on the main constituents of the essential oil representative samples of the extracted oil from each treatment were analysed in a semi-quantitative method using GLC (Perkin Elmer Autosampler 2000).

The extracted oil has been diluted with n-hexane, injected into a GLC using an auto-sampler and the different compounds have been separated on a HP-INNOWAX (60 x 0.25 x 0.25µm) capillary column. Helium was used as carrier gas (flow rate 1.5 ml min^{-1}). The temperature programme was: 35 °C to 230 °C (2.5 °C per min.) in course of time (92 min). Injector and flame ionisation detector temperatures were 250 °C and 300 °C, respectively. Area percentages were obtained using a PC programme (Maestro chromatography data system). For identification of single compounds internal and external standard substances have been used.

Two samples from each category of oil were also analysed by GC-MS; herb‘s
oil at vegetative stage, oil from the flowering stage and fruit oil. The compounds were identified by GC-MS under the following conditions:

GC: Varian 3400

● Injector: Gerstel Kaltaufgabesystem (KAS)

● Injection: 60 ^{o}C, temperature rate 10 ^{o}C sec^{-1} then up to 300 ^{o}C splitless, 60 sec.

● Column: Zebron ZB5-30, 30m x 0.25 mm. i.d. x 0.25 µm film thickness

● Temperature programme: 60 ^{o}C isotherm for 3 min, heating rate: 5 ^{o}C min^{-1} till 300 ^{o}C, then isotherm for 20 min.

● MS: Finnigan MAT SSQ 710

● Temperature: source: 150 ^{o}C

● Temperature manifold: 70 ^{o}C

● Electron multiplier voltage: 1800 v

● Dynode voltage: -5 kV

● Electron emission current: 200 µA.

● Electron energy: eV

2.6 Statistical analysis

The collected data were subjected to statistical analysis using the SAS programme (1985):

- Macro- and micronutrients in both soils and fennel herbs were subjected to statistical analysis using the one way ANOVA.
- Fennel growth parameters and yield statistical analysis using the General Linear Model (GLM) by using four replicates.

3 RESULTS

In order to interpret the differences in the growth, yield and essential oil of fennel, it was necessary to investigate the effect of the different treatments on soil fertility parameters: soil pH, available P, available K and DTPA extractable Fe, Mn, Zn and Cu. Also like other crops, yield and quality of fennel are also affected by plant macro- and micronutrients in the soils. Most of sandy soils in Egypt are generally poor in macro- and micronutrients. Hence, this study aims to investigate the effect of different sources of N, P and K on available plant nutrients in clay loam (Giza farm) and sandy soils (Sekem farm) under Egyptian conditions.

3.1 Effect of organic fertilization on available plant nutrients in soils

Soil fertility is the status of soil with respect to its ability to supply elements essential for plant growth at concentrations not toxic to the plant (Foth and Elias, 1996). Soil pH affects element availability and toxicity and root growth. It is one of the most important properties affecting soil fertility and is commonly managed to increase plant growth (Norland et al., 1991). Also the stability of metal-humic complex is pH dependent. On the other hand application of elemental S can decrease soil pH and increase the availability of macro- and micronutrients in the soil (El-Leboudi and Omer, 1975). Therefore it was necessary in this study to investigate the effect of organic fertilization on soil pH and available plant nutrients in soils.

The effect of organic fertilization on soil fertility parameters three weeks after the addition of the second portion of fertilization (first sample) and at fennel harvesting (second sample) in clay loam and sandy soils in the seasons (1998/1999) and (1999/2000) are given in the tables 7 to 14.

3.1.1 Soil pH

Soil pH data, three weeks after the addition of the second portion of fertilization (first sample) and at fennel harvesting (second sample) in clay loam (Giza farm) and sandy soils (Sekem farm) in both seasons, indicated that soil pH was not affected significantly by the different organic sources of nitrogen, phosphorus and potassium (tables 7, 8 and 9). On the other hand, generally soil pH slightly decreased in the second season compared with its values in the first season with all different sources of nitrogen, phosphorus and potassium.

Table 7: Effect of different nitrogen sources on soil pH

Treatments	Giza farm		Sekem farm	
	1998/99	1999/00	1998/99	1999/00
First sample				
Compost	8 a	8 a	7.7 a	7.7 a
Chicken manure	8 a	8 a	7.8 a	7.7 a
Compost/*Azotobacter*	8 a	8 a	7.7 a	7.7 a
Amm. nitrate (control)	8 a	8 a	7.6 a	7.7 a
Second sample				
Compost	8.2 a	8.1 a	7.8 a	7.7 a
Chicken manure	8.2 a	8.1 a	7.7 a	7.8 a
Compost/*Azotobacter*	8.2 a	8.1 a	7.7 a	7.7 a
Amm. nitrate (control)	8.2 a	8.1 a	7.8 a	7.8 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

Table 8: Effect of different phosphorus sources on soil pH

Treatments	Giza farm		Sekem farm	
	1998/99	1999/00	1998/99	1999/00
First sample				
Rock-P	8.0 a	8.0 a	7.8 a	7.7 a
Rock-P/S	8.0 a	8.0 a	7.6 a	7.6 a
Super-P (control)	8.0 a	8.0 a	7.6 a	7.6 a
Second sample				
Rock-P	8.2 a	8.1 a	7.7 a	7.8 a
Rock-P/S	8.2 a	8.1 a	7.8 a	7.7 a
Super-P (control)	8.2 a	8.1 a	7.7 a	7.7 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

Table 9: Effect of different potassium sources on soil pH

Treatments	Giza farm		Sekem farm	
	1998/99	1999/00	1998/99	1999/00
First sample				
Feldspar	8 a	8 a	7.6 a	7.7 a
Potass. sulphate (control)	8 a	8 a	7.9 a	7.7 a
Second sample				
Feldspar	8.2 a	8.1 a	7.7 a	7.8 a
Potass. sulphate (control)	8.2 a	8.1 a	7.8 a	7.7 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

3.1.2 Available phosphorus

Since chicken manure contained 2.9 % total P (and compost contained 0.5 % total P) (table 4) the fertilization with chicken manure resulted in excessive high levels of available phosphorus in the soil (Ohallorans et. al. 1993). An increase in the availability of phosphorus resulted also from fertilization with compost (Dormaar and Chang, 1995). Therefore it was necessary to investigate the effect of different nitrogen sources on available P in clay loam and sandy soils.

The different nitrogen sources significantly affected available phosphorus content in clay loam soil in all samples in both seasons except the first sample in the second season, while this effect was insignificant on sandy soil in both samples in both seasons (table 10). In the first season, fertilization with chicken manure on clay loam soil gave 42 % and 62 % more available phosphorus compared with ammonium nitrate in the first and second samples respectively. No significant differences were observed on available P due to fertilization with compost, compost/*Azotobacter* and ammonium nitrate in both samples. In the second season, the highest available phosphorus level was obtained from plots fertilized with compost/*Azotobacter*. Lesser available phosphorous has been found in those plots which had been fertilized with compost alone, chicken manure and least by ammonium nitrate. No significant differences were observed on available phosphorus levels due to fertilization with compost alone and compost with *Azotobacter*.

Table 10: Effect of different nitrogen sources on available phosphorus (mg kg^{-1})

Treatments	Giza farm		Sekem farm	
	1998/99	1999/00	1998/99	1999/00
First sample				
Compost	188 a	117 a	316 a	312 a
Chicken manure	251 b	101 a	345 a	342 a
Compost/*Azotobacter*	205 a	110 a	384 a	363 a
Amm. nitrate (control)	176 a	90 a	370 a	367 a
Second sample				
Compost	105 ab	104 ab	324 a	266 a
Chicken manure	122 b	99 ab	360 a	240 a
Compost/*Azotobacter*	100 ab	110 b	385 a	246 a
Amm. nitrate (control)	75 a	85 a	387 a	229 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

The effect of different phosphorus sources on available phosphorus in clay loam soil (Giza farm) was insignificant in both samples in both seasons except in the first sample in the first season. Application of superphosphate significantly increased the available phosphorus compared with rock-P alone and rock-P/S (table 11). The effect of different phosphorus sources on available phosphorus on sandy soil (Sekem farm) was significant in both seasons except in the second sample in 1999/2000. The highest available P was obtained from fertilization with superphosphate and the lowest was obtained from rock-P alone in both seasons. No significant differences were observed between fertilization with superphosphate and rock-P/S on available P in both seasons. Application of S (rock-P/S) significantly increased available P by 32 % and 20 % compared with rock-P alone in the first and second samples in 1998/99 respectively. The increments were 31 % and 17 % in the first and second samples in 1999/2000 respectively. Fertilization with superphosphate or rockphosphate with elemental sulphur (rock-P/S) on both soils were more effective in increasing the available P compared with rockphosphate alone.

Table 11: Effect of different phosphorus sources on available phosphorus (mg kg^{-1})

Treatments	Giza farm		Sekem farm	
	1998/99	1999/00	1998/99	1999/00
First sample				
Rock-P	200 a	91 a	261 a	267 a
Rock-P/S	203 a	110 a	382 b	386 b
Super-P (control)	211 b	104 a	418 b	384 b
Second sample				
Rock-P	106 a	105 a	311 a	230 a
Rock-P/S	109 a	104 a	390 b	280 a
Super-P (control)	109 a	103 a	390 b	210 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

3.1.3 Available potassium

Chicken manure contained 0.8 % total K and compost contained 2.4 % total K (table 4), therefore application of chicken manure increased the exchangeable K^+ in the soil (Ohallorans et al. 1993). Also an increase in the potassium concentration in the plant tissue resulted from fertilization with compost (Vidigal et al. 1995). Therefore, it was necessary to investigate the effect of different nitrogen sources on available K in clay loam and sandy soils.

Results in table 12 show that the effect of different nitrogen sources on available potassium in clay loam soil (Giza farm) was insignificant in the first sample and significant in the second sample in both seasons. The opposite was true on sandy soil (Sekem farm), the effect was significant in the first sample and insignificant in the second sample in both seasons. Fertilization with organic sources: compost, chicken manure and compost/*Azotobacter* increased available potassium in clay loam soil (Giza farm) significantly by 46 %, 21 % and 46 % in the first season and 33 %, 33 % and 43 % in the second season in comparison to fertilization with ammonium nitrate.

Table 12: Effect of different nitrogen sources on available potassium (mg kg^{-1})

Treatments	Giza farm		Sekem farm	
	1998/99	1999/00	1998/99	1999/00
First sample				
Compost	31 a	29 a	12 a	14 ab
Chicken manure	24 a	27 a	21 b	20 b
Compost/Azotobacter	25 a	28 a	16 ab	15 ab
Amm. nitrate (control)	24 a	23 a	10 a	8 a
Second sample				
Compost	35 b	28 b	6 a	12 a
Chicken manure	29 ab	28 b	7 a	14 a
Compost/Azotobacter	35 b	30 b	8 a	10 a
Amm. nitrate (control)	24 a	21 a	7 a	9 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

On sandy soil (Sekem farm), chicken manure significantly increased available potassium by 110 % and 150 % compared with ammonium nitrate in the first and second seasons respectively. Also fertilization with compost/*Azotobacter* gave 60 % and 80 % more available potassium than inorganic fertilization (ammonium nitrate) in the first and second seasons respectively. While fertilization with compost alone insignificantly increased available potassium by 20 % and 75 % in the first and second seasons respectively. Fertilization with compost and chicken manure were more effective in increasing the available K than ammonium nitrate. It is evident from table 13 that available potassium was higher in the clay loam soil (Giza farm) than in the sandy soil (Sekem farm) in both samples in both seasons and it was not affected significantly by different potassium sources in both samples in both seasons on both soils. Increasing available potassium in the plots fertilized with feldspar may be result from the higher content of total K in chicken manure and compost than its release from potassium feldspar.

Table 13: Effect of different potassium sources on available potassium (mg kg^{-1})

Treatments	Giza farm		Sekem farm	
	1998/99	1999/00	1998/99	1999/00
	First sample			
Feldspar	26 a	25 a	16 a	17 a
Potassium sulphate (CK)	26 a	28 a	18 a	19 a
	Second sample			
Feldspar	30 a	26 a	8 a	11 a
Potassium sulphate (CK)	31 a	28 a	9 a	14 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

3.1.4 Micronutrients

Because the organic sources (compost and chicken manure as natural nitrogen sources), rockphosphate as natural phosphorus source and feldspar as natural potassium source are rich in trace elements (see tables 4 and 5). It was necessary to investigate the effect of N, P and K sources on DTPA extractable Fe, Mn, Zn and Cu.

Nitrogen fertilization did not affect DTPA extractable Fe in both soils in both seasons except the second sample in sandy soil in 1998/99 (table 14). DTPA extractable soil Fe was significantly increased by 18 % and insignificantly by 12 % and 10 % compared with inorganic fertilizer after fertilization with chicken manure, compost/*Azotobacter* and compost alone respectively. It is evident from the same table 14 that nitrogen fertilization had an insignificant effect on DTPA extractable soil Mn and Zn in clay loam and sandy soils in both seasons.

Nitrogen fertilization significantly affected DTPA extractable soil Zn only in the first sample in 1998/99 and the second sample in 1999/2000 on clay loam soil, (table 14). Fertilization with chicken manure significantly increased DTPA extractable soil Zn by 35 % compared with ammonium nitrate in the first sample in 1998/99. At fennel harvesting in 1999/2000, DTPA extractable soil Zn significantly increased by 48 % and 29 % and insignificantly increased by 24 % after fertilization with compost alone, chicken manure and compost/*Azotobacter* compared with inorganic fertilization respectively.

Table 14: Effect of different nitrogen sources on DTPA extractable Fe, Mn, Zn and Cu

Treatments	Fe (mg kg-1)	Mn (mg kg-1)	Zn (mg kg-1)	Cu (mg kg-1)	Fe (mg kg-1)	Mn (mg kg-1)	Zn (mg kg-1)	Cu (mg kg-1)
	Giza farm				Sekem farm			
	First sample (1998/99)							
Compost	6 a	9 a	2.4 a	4 a	7 a	14 a	7 a	1.2 a
Chicken manure	6 a	10 a	3.5 b	4 a	7 a	15 a	7 a	1.4 a
Compost/Azotob.	6 a	8 a	2.7 a	5 a	7 a	15 a	8 a	1.5 a
Amm. nitrate (CK)	6 a	8 a	2.6 a	4 a	7 a	16 a	8 a	1.5 a
	Second sample (1998/99)							
Compost	7 a	23 a	4.0 a	4 a	8.1 ab	11 a	7 a	1.3 a
Chicken manure	7 a	23 a	5.0 a	4 a	8.7 b	12 a	8 a	1.7 a
Compost/Azotob.	7 a	23 a	4.0 a	4 a	8.3 ab	12 a	8 a	1.5 a
Amm. nitrate (CK)	7 a	21 a	3.5 a	4 a	7.4 a	12 a	7 a	1.7 a
	First sample (1999/00)							
Compost	8 a	26 a	4 a	3.8 a	7 a	13 a	6 a	1.2 a
Chicken manure	8 a	23 a	4 a	3.5 a	7 a	14 a	7 a	1.4 a
Compost/Azotob.	7 a	28 a	3 a	3.4 a	7 a	14 a	7 a	1.5 a
Amm. nitrate (CK)	8 a	23 a	3 a	3.6 a	7 a	15 a	7 a	1.4 a
	Second sample (1999/00)							
Compost	7 a	10 a	3.1 b	3.2 a	6 a	11 a	4 a	1.2 a
Chicken manure	7 a	9 a	2.7 b	3.1 a	6 a	11 a	4 a	1.4 a
Compost/Azotob.	7 a	9 a	2.6 ab	3.2 a	6 a	11 a	4 a	1.5 a
Amm. nitrate (CK)	7 a	8 a	2.1 a	3.2 a	6 a	12 a	4 a	1.5 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

The effect of different phosphorus sources on DTPA extractable soil Fe in clay loam soil (Giza farm) was significant only in the second sample in both seasons. On the other hand, the effect of different phosphorus sources on DTPA extractable soil Fe was significant only in the first sample in both seasons in sandy soil (table 15). The higher values of DTPA extractable soil Fe were obtained from the plots fertilized with superphosphate then by rock-P/S and the lowest values from plots fertilized by rock-P alone on both soils. Fertilization with rock-P/S increased DTPA extractable soil Fe by 5 % and 12 % compared with rock-P alone in the first sample in the first and second seasons respectively. Generally no significant differences were observed between rock-P/S and superphosphate on DTPA extractable soil Fe in both seasons in both soils. Fertilization with superphosphate was more effective to increasing DTPA extractable soil Fe in both soils than rockphosphate alone or mixed with elemental sulphur.

Table 15: Effect of different phosphorus sources on DTPA extractable Fe, Mn, Zn and Cu

Treatments	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})
	Giza farm				Sekem farm			
First sample (1998/99)								
Rock-P	6.0 a	8.5 a	2.8 a	4 a	6.5 a	13 a	6 a	1.2 a
Rock-P/S	6.0 a	9.0 a	2.8 a	4 a	6.8 b	16 b	8 a	1.6 a
Super-P (control)	6.0 a	8.0 a	2.8 a	4 a	7.3 b	15 b	8 a	1.5 a
Second sample (1998/99)								
Rock-P	6.2 a	25 b	4.3 a	4 a	7.8 a	11 a	7 a	1.2 a
Rock-P/S	6.7 b	20 a	3.8 a	4 a	8.2 a	12 a	8 a	1.5 a
Super-P (control)	6.9 b	24 ab	4.0 a	4 a	8.6 a	12 a	8 a	1.4 a
First sample (1999/00)								
Rock-P	8.5 a	20 a	3.9 a	4 a	6.0 a	12 a	5 a	1.5 a
Rock-P/S	7.5 a	22 a	3.1 a	4 a	7.3 b	16 b	8 b	1.7 a
Super-P (control)	7.6 a	25 a	3.4 a	4 a	7.4 b	14 b	8 b	1.6 a
Second sample (1999/00)								
Rock-P	6.5 a	10 a	3.1 a	3 a	5.2 a	11 a	4 a	1.2 a
Rock-P/S	6.4 a	9 a	2.8 a	3 a	6.8 a	12 a	5 a	1.4 a
Super-P (control)	6.8 b	9 a	2.6 a	3 a	5.7 a	11 a	5 a	1.7 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

DTPA extractable soil Mn in clay loam was not affected by the different phosphorus sources except the second sample in the first season 1998/1999 where the data showed that phosphorus in the form of rockphosphate increased DTPA extractable soil Mn over those fertilized with superphosphate and rock-P/S (table 15). In sandy soil DTPA extractable Mn was affected significantly by the different phosphorus sources only in the first sample in both seasons. The highest level of DTPA extractable soil Mn was obtained after fertilization with rock-P/S followed by fertilization with superphosphate and the least amount of available Mn had been found in the soil fertilized with rock-P alone in both seasons. Fertilization with rock-P/S increased significantly DTPA extractable soil Mn by 19 % and 25 % compared with rock-P fertilization in the first sample in the first and second seasons respectively.

In clay loam soil no differences could be found for DTPA extractable Zn due to fertilization with different phosphorus sources except in the samples taken at the fennel harvesting in the second season. In 1999/2000, the data showed that phosphorus in the form of rockphosphate gave higher values for DTPA extractable soil Zn compared with soil samples fertilized with superphosphate and rock-P/S (table 15). The effect of different phosphorus sources on DTPA extractable soil Zn was significant in sandy soil in both seasons except the second sample in the second season. In the plots fertilized with rock-P/S similar DTPA extractable soil Zn had been measured like in those fertilized with superphosphate in both seasons. While the lowest level was obtained from plots fertilized with rock-P alone. Fertilization with rock-P/S increased DTPA extractable soil Zn by 33 % and 14 % in the first season and 38 % and 25 % in the second season compared with the content of the plots fertilized with rock-P alone in the first and second samples respectively. DTPA extractable soil Cu was not affected by the different phosphorus sources in both seasons on both soils (table 15). It is evident from table 16 that DTPA extractable soil Fe, Mn, Zn and Cu were not significantly affected by different potassium sources in both seasons in both soils.

Table 16: Effect of different potassium sources on DTPA extractable Fe, Mn, Zn and Cu

Treatments	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})
	Giza farm				Sekem farm			
First sample (98/99)								
Feldspar	6.1 a	8.6 a	2.9 a	4.0 a	7 a	15 a	8 a	1.6 a
K_2SO_4 (control)	6.0 a	8.0 a	2.7 a	4.0 a	7 a	14 a	7 a	1.2 a
Second sample (98/99)								
Feldspar	6.5 a	22 a	4.1 a	3.7 a	8 a	12 a	8 a	1.9 a
K_2SO_4 (control)	6.6 a	23 a	3.8 a	3.8 a	8 a	11 a	7 a	1.5 a
First sample (99/00)								
Feldspar	7.3 a	21 a	3.2 a	3.5 a	7 a	14 a	7 a	1.6 a
K_2SO_4 (control)	8.1 a	23 a	3.7 a	3.7 a	7 a	14 a	7 a	1.2 a
Second sample (99/00)								
Feldspar	6.6 a	10 a	2.6 a	3.2 a	6 a	11 a	4 a	1.4 a
K_2SO_4 (control)	6.9 a	9 a	2.7 a	3.2 a	6 a	14 a	4 a	1.4 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

3.2 Effect of organic fertilization on the nutrient contents in fennel herb

3.2.1 Effect of different nitrogen sources

The effect of different nitrogen sources was insignificant on total contents of N, P, K, Ca and Mg in the fennel herb in both seasons and on both soils except the content of total K in the herb of the plants grown on the Giza farm in both seasons. Fertilization with compost alone or compost/*Azotobacter* significantly increased total K content compared to fertilization with ammonium nitrate (table 17).

The effect of different nitrogen sources was insignificant on the total content of micronutrients (Fe, Mn, Zn, and Cu) in the fennel herb in both seasons and on both soils except total Mn in the herb of the plants grown on the Giza farm in 1998/1999, total Zn in the second season (1999/2000) in the plants grown on either soil (table 18). Fertilization with compost or chicken manure gave higher Mn and Zn than fertilization with ammonium nitrate.

Table 17: Effect of different nitrogen sources on total content of macronutrients in the fennel herbs

Treatments	Giza farm		Sekem farm	
	98/99	99/00	98/99	99/00
Nitrogen (mg g^{-1})				
Compost	37.0 a	44.6 a	32.1 a	40.5 a
Chicken manure	33.4 a	43.0 a	32.7 a	43.3 a
Compost/Azotob.	36.1 a	42.2 a	33.2 a	39.6 a
Amm. nitrate (CK)	35.3 a	43.8 a	31.4 a	38.3 a
Phosphorus (mg g^{-1})				
Compost	5.0 a	5.0 a	6.5 a	6.2 a
Chicken manure	4.9 a	5.5 a	6.9 a	6.4 a
Compost/Azotob.	4.6 a	5.1 a	6.8 a	6.5 a
Amm. nitrate (CK)	4.8 a	5.1 a	6.6 a	6.2 a
Potassium (mg g^{-1})				
Compost	45.3 ab	38.5 b	46.2 a	46.0 a
Chicken manure	37.1 a	29.8 ab	50.1 a	51.0 a
Compost/Azotob.	50.1 b	33.8 ab	46.0 a	52.9 a
Amm. nitrate (CK)	37.5 a	27.7 a	51.2 a	44.0 a
Calcium (mg g^{-1})				
Compost	19.7 a	24.6 a	24.3 a	21.8 a
Chicken manure	17.5 a	20.6 a	22.0 a	21.9 a
Compost/Azotob.	21.7 a	22.3 a	21.9 a	21.8 a
Amm. nitrate (CK)	17.6 a	19.8 a	24.1 a	21.1 a
Magnesium (mg g^{-1})				
Compost	3.4 a	2.3 a	2.3 a	2.2 a
Chicken manure	3.7 a	2.8 a	2.2 a	2.2 a
Compost/Azotob.	3.0 a	2.7 a	2.3 a	2.8 a
Amm. nitrate (CK)	3.3 a	2.5 a	2.2 a	2.2 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

Table 18: Effect of different nitrogen sources on total content of micronutrients in the fennel herbs

Treatments	Giza farm		Sekem farm	
	1998/99	1999/2000	1998/99	1999/2000
Fe (mg kg^{-1})				
Compost	3087 a	1638 a	1692 a	2180 a
Chicken manure	2688 a	1415 a	1750 a	1953 a
Compost/Azotob.	2288 a	1451 a	1698 a	2189 a
Amm. nitrate (CK)	2994 a	1518 a	1763 a	2132 a
Mn (mg kg^{-1})				
Compost	36.1 a	59.8 a	50.5 a	48.7 a
Chicken manure	36.5 a	49.2 a	54.5 a	42.7 a
Compost/Azotob.	42.8 b	54.3 a	50.5 a	45.5 a
Amm. nitrate (CK)	40.9 ab	51.6 a	51.8 a	50.6 a
Zn (mg kg^{-1})				
Compost	44.8 a	48.2 a	43.0 a	43.6 ab
Chicken manure	47.7 a	59.4 b	43.3 a	41.3 ab
Compost/Azotob.	43.1 a	45.5 a	44.1 a	45.0 b
Amm. nitrate (CK)	45.7 a	49.2 a	44.8 a	38.9 a
Cu (mg kg^{-1})				
Compost	16.3 a	12.6 a	8.1 a	9.7 a
Chicken manure	16.8 a	13.6 a	9.9 a	10.3 a
Compost/Azotob.	15.9 a	12.9 a	7.3 a	9.4 a
Amm. nitrate (CK)	16.0 a	12.8 a	8.7 a	10.1 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

3.2.2 Effect of different phosphorus sources

The total content of macro- and micronutrients in the fennel herb was not significantly affected due to the different P sources in both seasons and on both soils (tables 19 and 20).

Table 19: Effect of different phosphorus sources on total content of macronutrients in the fennel herbs

Treatments	Giza farm		Sekem farm	
	1998/99	1999/2000	1998/99	1999/2000
Phosphorus (mg g^{-1})				
Rock-P	4.3 a	5.6 a	6.3 a	6.1 a
Rock-P/S	5.0 a	4.9 a	6.9 a	6.1 a
Super-P (control)	5.1 a	5.0 a	6.8 a	6.8 a
Calcium (mg g^{-1})				
Rock-P	19.2 a	22.8 a	24.0 a	22.5 a
Rock-P/S	18.8 a	21.4 a	21.9 a	21.1 a
Super-P (control)	19.1 a	21.4 a	23.4 a	21.3 a
Magnesium (mg g^{-1})				
Rock-P	3.4 a	2.4 a	2.2 a	2.2 a
Rock-P/S	3.2 a	3.0 a	2.2 a	2.7 a
Super-P (control)	3.4 a	2.4 a	2.3 a	2.2 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

Table 20: Effect of different phosphorus sources on total content of micronutrients in the fennel herbs

Treatments	Giza farm		Sekem farm	
	1998/99	1999/2000	1998/99	1999/2000
Fe (mg kg^{-1})				
Rock-P	2933 a	1520 a	1752 a	2271 a
Rock-P/S	3096 a	1530 a	1660 a	2095 a
Super-P (control)	2261 a	1466 a	1766 a	2012 a
Mn (mg kg^{-1})				
Rock-P	38.8 a	61.3 a	52.3 a	46.7 a
Rock-P/S	38.5 a	50.3 a	52.6 a	42.1 a
Super-P (control)	40.0 a	49.6 a	50.6 a	51.9 a
Zn (mg kg^{-1})				
Rock-P	47.4 a	52.8 a	44.0 a	44.1 a
Rock-P/S	43.8 a	52.8 a	43.3 a	40.8 a
Super-P (control)	44.9 a	46.2 a	44.1 a	41.7 a
Cu (mg kg^{-1})				
Rock-P	18.9 a	13.9 a	9.4 a	10.4 a
Rock-P/S	17.8 a	12.7 a	7.3 a	9.8 a
Super-P (control)	14.7 a	12.3 a	8.8 a	9.4 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

3.2.3 Effect of different potassium sources

The total contents of macro- and micronutrients in the fennel herbs were not significantly affected by the different K sources in both seasons and on both soils (tables 21 and 22).

Table 21: Effect of different potassium sources on total content of macronutrients in the fennel herbs

Treatments	Giza farm		Sekem farm	
	1998/99	1999/2000	1998/99	1999/2000
Potassium (mg g^{-1})				
Feldspar	39.8 a	31.9 a	49.2 a	48.2 a
K_2SO_4 (control)	45.2 a	32.9 a	47.5 a	48.7 a
Calcium (mg g^{-1})				
Feldspar	19.1 a	20.9 a	23.2 a	22.3 a
K_2SO_4 (control)	19.1 a	22.8 a	23.0 a	21.1 a
Magnesium (mg g^{-1})				
Feldspar	2.5 a	2.3 a	2.2 a	2.2 a
K_2SO_4 (control)	2.1 a	2.8 a	2.3 a	2.5 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

Table 22: Effect of different potassium sources on total content of micronutrients in the fennel herbs

Treatments	Giza farm		Sekem farm	
	1998/99	1999/2000	1998/99	1999/2000
Fe (mg kg^{-1})				
Feldspar	1937 a	1372 a	1711 a	2176 a
K_2SO_4 (control)	2013 a	1638 a	1740 a	2052 a
Mn (mg kg^{-1})				
Feldspar	39.1 a	49.2 a	50.7 a	49.3 a
K_2SO_4 (control)	39.0 a	58.2 a	52.9 a	44.4 a
Zn (mg kg^{-1})				
Feldspar	47.1 a	49.8 a	43.6 a	43.3 a
K_2SO_4 (control)	43.6 a	51.3 a	43.9 a	41.1 a
Cu (mg kg^{-1})				
Feldspar	21.7 a	13.4 a	8.1 a	9.9 a
K_2SO_4 (control)	15.8 a	12.4 a	8.9 a	9.9 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

3.3 Effect of different organic fertilization on fennel growth

3.3.1 Effect of different nitrogen sources

In all plants, N is a constituent of chlorophyll, all proteins including the enzymes, and many other compounds. A lack of N causes leaves to become yellow and stuns growth, but conversely with an adequate supply of N, vegetative growth is rapid and foliage dark green in colour. The large need of plants for N and the limited ability of soils to supply available N cause N to be the most limiting nutrient for all crops production (Olsen and Kurtz, 1982 and Foth and Ellis, 1996). To interpret the differences between treatments in the yield of fennel plants, i.e. fruit and essential oil yields, it was necessary to investigate the effect of the different treatments on the plant height, number of branches per plant, dry weight and fruit yield per plant.

Fennel plant height at vegetative, flowering and maturity stages was not affected significantly by the different forms of nitrogen fertilizers in both seasons and on both farms except in the second season on Giza farm (table 23). Generally fertilization with chemical fertilizer (ammonium nitrate) on both farms in both seasons gave the tallest fennel plants followed by fertilization with compost/*Azotobacter*, compost and chicken manure gave the shortest. The effect of fertilization with different nitrogen sources on the number of branches per plant was significant at all fennel growth stages on Giza farm and only at maturity stage on Sekem farm in the first season (table 24). Generally fertilization with ammonium nitrate gave the highest numbers of branches per plant followed by compost/*Azotobacter*, chicken manure and compost alone gave the lowest. In the case of organic sources, chicken manure and compost/*Azotobacter* were more effective in increasing the number of branches per plant compared with compost alone on both types of soils (Giza and Sekem farms).

Table 23: Effect of different nitrogen sources on fennel plant height (cm)

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Vegetative stage				
Compost	90 a	114 bc	92 a	114 a
Chicken manure	97 a	109 a	96 a	120 a
Compost/Azotob.	95 a	113 b	99 a	115 a
Amm. nitrate (CK)	96 a	118 c	105 a	121 a
Flowering stage				
Compost	142 a	154 a	124 a	126 a
Chicken manure	142 a	156 a	125 a	135 a
Compost/Azotob.	145 a	162 b	125 a	129 a
Amm. nitrate (CK)	148 a	168 c	129 a	132 a
Maturity stage				
Compost	145 a	155 a	134 a	129 a
Chicken manure	137 a	152 a	132 a	136 a
Compost/Azotob.	135 a	156 ab	132 a	137 a
Amm. nitrate (CK)	136 a	164 b	139 a	138 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

Table 24: Effect of different nitrogen sources on number of branches per plant

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Vegetative stage				
Compost	5.0 a	5.7 ab	5.0 a	5.3 a
Chicken manure	5.9 bc	5.2 a	5.1 a	5.2 a
Compost/Azotob.	5.6 b	5.9 b	5.4 a	5.3 a
Amm. nitrate (CK)	6.4 c	6.3 b	5.3 a	6.0 b
Flowering stage				
Compost	7.1 a	7.1 a	5.8 a	5.9 a
Chicken manure	7.4 b	6.4 a	6.0 a	5.9 a
Compost/Azotob.	7.9 b	7.5 a	6.2 a	6.2 ab
Amm. nitrate (CK)	7.6 b	7.1 a	6.6 a	6.9 b
Maturity stage				
Compost	9.7 b	7.1 a	6.8 a	7.5 a
Chicken manure	7.1 a	6.3 a	7.3 a	8.2 a
Compost/Azotob.	9.8 b	7.4 a	7.2 a	8.3 a
Amm. nitrate (CK)	9.0 b	7.1 a	7.8 b	9.1 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

The dry weight of fennel plants was significantly affected by different nitrogen sources at the vegetative stage in both seasons and on both farms (table 25). At fennel vegetative stage on Giza farm in the first season, the largest fennel dry weight (g plant^{-1}) was obtained after ammonium nitrate fertilization followed by chicken manure, compost/*Azotobacter* and compost alone gave the lowest. While in the second season, fertilization with compost/*Azotobacter* gave 93 % from the dry weight of the plots fertilized with ammonium nitrate. The largest dry weight of fennel plants at vegetative stage on Sekem farm was obtained on plots fertilized with ammonium nitrate in both seasons. Fertilization with chicken manure and compost/*Azotobacter* gave no effect on the dry weight of fennel at vegetative stage in both seasons. Fertilization with compost/ *Azotobacter* increased the dry weight of fennel plants by 17 % and 12 % compared to the plots fertilized with compost alone in the first and second season respectively.

On the Giza farm the largest fennel dry weight at flowering stage was obtained by fertilization with chicken manure in the first season and by fertilization with compost/*Azotobacter* in the second season. While on Sekem farm the largest dry weight was obtained by fertilization with ammonium nitrate followed by fertilization with chicken manure, compost/*Azotobacter* and compost alone gave the lowest dry weights.

Table 25: Effect of different nitrogen sources on fennel dry weight (g plant^{-1})

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Vegetative stage				
Compost	155 a	156 a	60 a	97 a
Chicken manure	182 c	153 a	70 b	112 b
Compost/Azotob.	172 b	192 b	72 b	110 b
Amm. nitrate (CK)	194 d	206 c	73 b	130 c
Flowering stage				
Compost	229 a	200 a	264 a	144 a
Chicken manure	241 b	197 a	247 a	185 c
Compost/Azotob.	229 a	264 c	258 a	165 b
Amm. nitrate (CK)	227 a	232 b	271 a	200 c
Maturity stage				
Compost	284 c	298 a	263 a	345 a
Chicken manure	203 a	279 a	266 a	404 ab
Compost/Azotob.	267 b	303 a	263 a	445 b
Amm. nitrate (CK)	267 b	274 a	314 a	430 b

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

At maturity stage, the effect of different nitrogen sources on dry weight of fennel plants was significant only on Giza farm in the first season and on Sekem farm in the second season (table 25). On Giza farm, the largest dry weight of fennel was obtained with plants grown on the plots fertilized with compost alone followed by compost/*Azotobacter*, ammonium nitrate and chicken manure gave the lowest dry weights. On Sekem farm in the second season, the largest dry weight of fennel was obtained with plants grown on the plots fertilized with compost/*Azotobacter*, ammonium nitrate, chicken manure and compost alone gave the lowest.
The largest fruit yields per plant were been obtained on clay loam soil (Giza farm) after fertilization with ammonium nitrate followed by compost/*Azotobacter*, chicken manure and compost alone gave the lowest yields in the first season (Fig. 3-1).

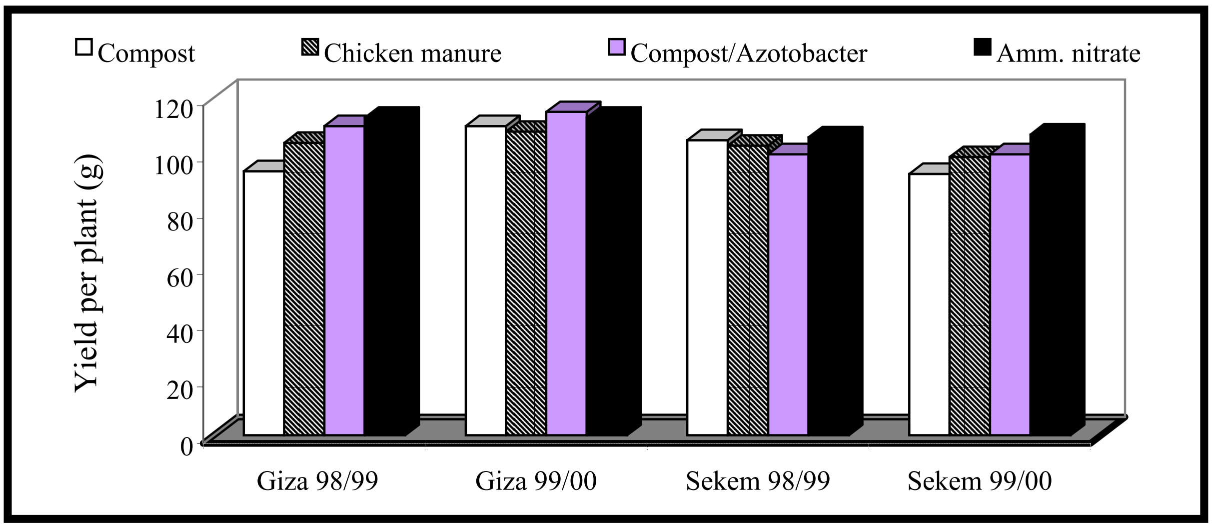

Fig. 3-1: Effect of different nitrogen sources on the fennel fruit yields (g plant^{-1})

Fertilization with compost/*Azotobacter* significantly increased the fennel yields per plant by 16 % compared with fertilization with compost alone. No significant differences on fennel fruits per plant were observed between fertilization with ammonium nitrate and compost/*Azotobacter* on clay loam soil in the first season. Fertilization with chicken manure gave minus 8 % from that yield of plants grown on plots fertilized with ammonium nitrate. On the other hand, the effect of different nitrogen sources was insignificant on fennel fruits per plant on clay loam soil in the second season. The effect of different nitrogen forms on the fruit yield per plant was significant on Sekem farm in both seasons.

Fertilization with ammonium nitrate gave significantly higher fennel fruit yields per plant than after fertilization with compost or chicken manure. No significant differences were observed on yields per plant due to fertilization with compost, chicken manure and ammonium nitrate in the first season. While inoculating with *Azotobacter* significantly decreased fennel fruits per plant by 5 % and 6 % compared with plants grown on the plots fertilized with compost alone and ammonium nitrate respectively. In the second season, the largest fruit yields per plant were obtained after fertilization with ammonium nitrate followed by fertilization with compost/*Azotobacter*, chicken manure and compost alone gave the lowest yields. Inoculating with *Azotobacter* insignificantly increased the yields per plant by 6 % compared with the yield of plants fertilized with compost alone.

It can be summarised that the largest fennel growth was obtained after fertilization with ammonium nitrate on both soils followed by fertilization with compost/*Azotobacter*, chicken manure and compost alone gave the lowest yields. In the case of organic nitrogen sources, compost/*Azotobacter* and chicken manure were effective in increasing the fennel growth on both soils compared with fertilization with compost alone.

3.3.2 Effect of different phosphorus sources on fennel growth

When scientists began to add nutrients to soils to improve their fertility, phosphorus (**P**) was soon discovered to be one of the limiting elements. Indeed, P became known as the master key to agriculture because lack of available P in soils limited the growth of both cultivated and uncultivated plants (Foth and Ellis, 1996). Different phosphorus sources can influence the plant growth (Naik et al. 1993). Also rockphosphate is as effective as single superphosphate in improving growth and yield of medicinal plants (Sastry et al. 1997). On the other hand, application of elemental sulphur can affect not only pH in the soil but also plant growth and its yield (El-Leboudi and Omer 1975, Khalaf and Taha 1988 and Salem et al. 1986). To interpret the differences between treatments (rock-P alone, rock-P/S and superphosphate) in the yield of fennel, i.e. fruits and essential oil, it was necessary to investigate the effect of the different treatments on the plant height, number of branches per plant, dry weight of fennel and fruit yields per plant during their growth stages like with nitrogen fertilization.

The effect of different phosphorus sources on fennel plant height at vegetative stage on both farms was significant in both seasons except in the first season on Sekem farm (table 26). The tallest plants were obtained after fertilization with superphosphate followed by rock-P/S, and rock-P alone gave the shortest plants. But the differences observed due to fertilization with rock-P/S and superphosphate on fennel plant height at all fennel growth stages on both soils in both seasons generally were not significant. Fertilization with rock-P/S on sandy soil gave 11% and 7 % taller plants at vegetative stage than plots fertilized with rock-P alone in the first and second season respectively. The effect of phosphorus forms on the fennel plant height at flowering and maturity stage on both soils was insignificant in both seasons except on the sandy soil in 1999/2000, where fertilization with rock-P/S or superphosphate increased significantly the fennel plant height by 9 % in comparison with the height of plants grown on the plots fertilized with rock-P alone.

The number of branches per plant at vegetative stage was not affected by phosphorus fertilization on both soils in the first season (table 27). While fertilization with rock-P/S on clay loam soil increased significantly the number of branches by 11 % compared with fertilization with rockphosphate alone. No significant differences were observed between plots fertilized with rock-P/S and superphosphate on the number of branches per plant at vegetative stage on clay loam in the second season. While fertilization with superphosphate on the sandy soil increased the number of branches by 12 % and 10 % compared with rock-P and rock-P/S respectively.

Table 26: Effect of different phosphorus sources on fennel plant height (cm)

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Vegetative stage				
Rock-P	92 a	110 a	89 a	112 a
Rock-P/S	94 a	115 b	99 a	120 b
Super-P (control)	98 b	116 b	98 a	120 b
Flowering stage				
Rock-P	137 a	158 a	131 a	123 a
Rock-P/S	138 a	158 a	130 a	134 b
Super-P (control)	143 a	151 a	135 a	134 b
Maturity stage				
Rock-P	142 a	159 a	139 a	129 a
Rock-P/S	146 a	160 a	135 a	135 a
Super-P (control)	147 a	155 a	138 a	136 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

Table 27: Effect of different phosphorus sources on number of branches per plant

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Vegetative stage				
Rock-P	5.5 a	5.3 a	5.0 a	5.2 a
Rock-P/S	6.0 a	5.9 b	5.2 a	5.3 a
Super-P (control)	5.7 a	6.0 b	5.5 a	5.9 b
Flowering stage				
Rock-P	7.0 a	6.8 a	5.5 a	5.7 a
Rock-P/S	7.1 a	7.5 a	6.1 ab	6.2 ab
Super-P (control)	7.8 b	6.8 a	6.8 b	6.8 b
Maturity stage				
Rock-P	7.3 a	6.6 a	6.9 a	8.0 a
Rock-P/S	9.4 b	7.6 b	7.8 b	8.8 a
Super-P (control)	9.6 b	6.8 a	7.2 a	8.1 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

The effect of different phosphorus sources on the number of branches per plant at flowering stage was significant on both soils in both seasons except in the second season on Giza farm. The highest number of branches per fennel plant at flowering stage on both soils was obtained after fertilization with superphosphate followed by rock-P/S and rock-P alone had the lowest effect.

At maturity stage, the highest number of branches per plant was obtained after fertilization with rock-P/S in both seasons and on both farms except on Giza farm in 1998/99 with the plants grown on the plots fertilized with superphosphate having the largest effect. Fertilization with rock-P/S on Giza farm resulted in 29 % and 15 % more branches per plant than fertilization with rock-P alone in the first and second season respectively.

Phosphorus fertilization on Sekem farm significantly affected the number of branches per plant at maturity stage in the first season, while this effect was insignificant in the second season (table 27). Fertilization with rock-P/S significantly increased the number of branches by 12 % compared to fertilization with rockphosphate alone. Phosphorus sources had a significant effect on fennel dry weight at all fennel stages on Giza farm in both season (table 28). The fertilization with rock-P/S increased the fennel herb dry weight at vegetative stage by 10 % and 5 % compared with plants fertilized with rock-P alone on Giza farm in the first and second season respectively. The increments were 23 % and 20 % at flowering stage and 16 % and 5 % at maturity stage. It can be summarised that fertilization with rockphosphate mixed with elemental sulphur on the clay loam soil (Giza farm) gave the largest dry weight of fennel at all growth stages followed by superphosphate and rock-P alone gave the lowest.

Plant dry weight on Sekem farm was significantly affected by phosphorus sources at all growth stage in both seasons (table 28). The largest dry weights at all growth stages were obtained from plants grown on the plots fertilized with superphosphate followed by fertilization with rock-P/S and rock-P alone gave the lowest. Application of elemental sulphur (rock-P/S) increased the fennel dry weight at vegetative stage by 32 % and 17 % compared to fertilization with rock-P alone in the first and second season respectively. The increments were 7 % and 30 % at flowering stage and 18 % and 18 % at maturity stage in the first and second season respectively. Fertilization with rock-P/S resulted in 5 % and 15 % less dry weight at flowering stage and 9 % and 6 % at maturity stage than obtained after fertilization with superphosphate in the first and second season respectively.

Table 28: Effect of different phosphorus sources on fennel dry weight (g $plant^{-1}$)

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Vegetative stage				
Rock-P	168 a	171 a	52 a	95 a
Rock-P/S	185 c	180 b	76 b	112 b
Super-P (control)	176 b	180 b	79 b	132 c
Flowering stage				
Rock-P	207 a	198 a	244 a	126 a
Rock-P/S	255 c	237 b	261 ab	180 b
Super-P (control)	233 b	235 b	276 b	212 c
Maturity stage				
Rock-P	235 a	273 a	257 a	341 a
Rock-P/S	272 b	305 b	273 a	417 b
Super-P (control)	260 b	291 ab	300 b	445 b

Numbers with different characters are statistically different at the 5 % level by the Tukey test

Phosphorus fertilization had a significant effect on the yield of fennel fruits (g $plant^{-1}$) in both seasons and on both farms. The largest yields were obtained after fertilization with superphosphate followed by rock-P/S, while rockphosphate alone gave the lowest yields on both soils in both seasons except on Giza farm, where fertilization with rockphosphate mixed with elemental sulphur (rock-P/S) gave 6 % more compared with the yield of plants grown on the plots fertilized with superphosphate (Fig.3-2). Application of rockphosphate with elemental sulphur significantly increased the yield of fennel fruits per plant by 6 % over the yield from plots fertilized with rockphosphate alone on Giza farm in the second season. The increments were 2 % and 11 % on Sekem farm in the first and second season respectively.

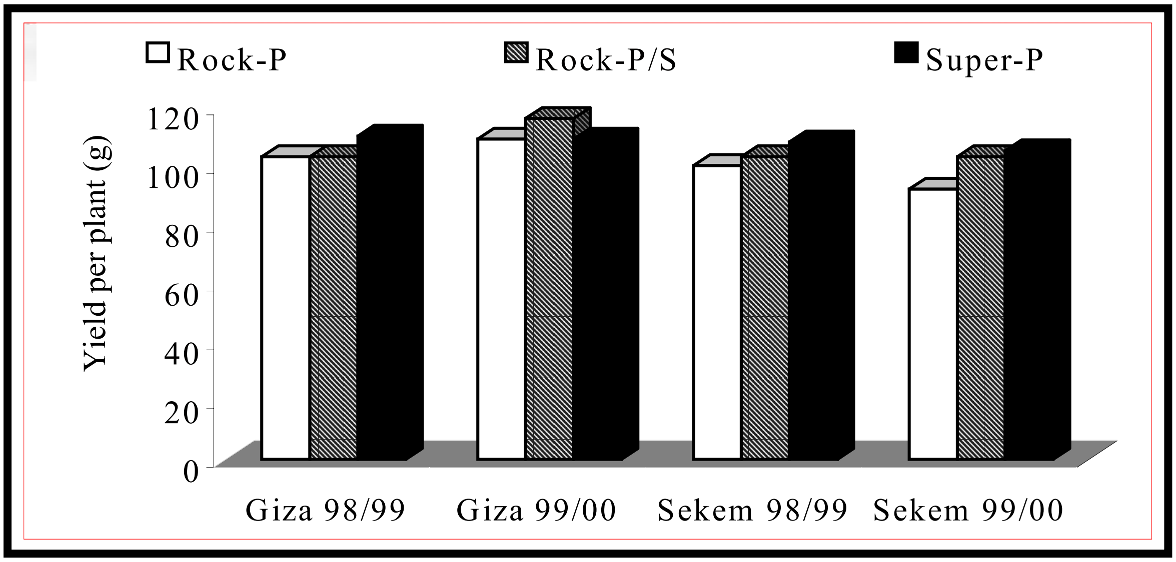

Fig 3-2: Effect of different phosphorus sources on the fennel fruit yields (g $plant^{-1}$)

3.3.3 Effect of different potassium sources on fennel growth

Potassium is a macronutrient which's essentiality for plant growth is known since the work of von Liebig, published in 1840 (Foth and Ellias, 1996). Potassium is associated with many enzymes involved in photosynthesis, organic compound synthesis and translocation of organic compounds. Generally, soils are different in their ability to supply K for plants, also plants grown on different kinds of soils with the same content of exchangeable K may take up different amounts of K during their growing season. Moreover the potassium sources release different amounts of available potassium into the soil (Foth and Ellias, 1996). The K availability for plants supplied as different potassium sources depend on soil types and environmental conditions (Sparks and Huang, 1985). To interpret the differences in the yield of fruits and essential oil of fennel plants due to different treatments (feldspar and potassium sulphate), it was necessary to investigate the effect of the different treatments on the plant height, number of branches per plant and dry weight of fennel during their growth stages on clay loam and sandy soil under Egyptian conditions like already discussed for nitrogen and phosphorous.

Potassium fertilization on both farms had no significant effect on fennel plant height during the three fennel periods of its growing cycle except at flowering and maturity stages on Sekem farm in the first season (table 29). In the first season, fennel plant heights at flowering and maturity stages were 6% and 5 % taller on the plots fertilized with feldspar than after growth on the plots fertilized with potassium sulphate.

Table 29: Effect of different potassium sources on fennel plant height (cm)

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Vegetative stage				
Feldspar	95 a	112 a	94 a	116 a
Potass. sulphate (CK)	94 a	115 a	99 a	118 a
Flowering stage				
Feldspar	141 a	163 a	130 b	129 a
Potass. sulphate (CK)	145 a	157 a	123 a	131 a
Maturity stage				
Feldspar	137 a	158 a	137 b	129 a
Potass. sulphate (CK)	139 a	155 a	131 a	135 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

Potassium fertilization on Giza farm resulted in significant differences in the number of branches per plant only at vegetative stage in both seasons and at maturity stage in the first season (table 30). The number of branches per plant was only higher in the plots fertilized with feldspar than those fertilized with potassium sulphate at vegetative stage in the first season. While fertilization with potassium sulphate gave 9 % and 16 % more branches than did feldspar at maturity stage of the plants in the first season and at vegetative stage in the second season respectively. Results recorded during two growing seasons on Sekem farm showed that the different potassium sources had an insignificant effect on the number of branches per plant in both seasons except at vegetative stage in the first season. Potassium sulphate gave 10 % more branches than did feldspar.

Table 30: Effect of different potassium sources on number of branches per plant

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Vegetative stage				
Feldspar	6.3 b	5.3 a	4.9 a	5.3 a
Potass. sulphate (CK)	5.2 a	6.3 b	5.4 b	5.5 a
Flowering stage				
Feldspar	7.3 a	7.1 a	6.4 a	6.2 a
Potass. sulphate (CK)	7.3 a	7.0 a	6.0 a	6.3 a
Maturity stage				
Feldspar	8.5 a	7.1 a	7.4 a	8.5 a
Potass. sulphate (CK)	9.3 b	7.2 a	7.2 a	8.1 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

Fennel plant height was affected significantly by the different potassium sources on Nile valley soil (Giza farm) at vegetative stage in both seasons, at flowering stage in the first season and at maturity stage in the second season (table 31). Dry weight (g plant^{-1}) was 6 %, 7 % and 1 % higher in the plots fertilized with potassium sulphate on Giza farm than in the plots receiving feldspar at vegetative, flowering and maturity stages respectively in the first season. In the second season fertilization with feldspar gave the largest dry weight at maturity stage. It gave 8 % more than in the plots fertilized with potassium sulphate. The effect of potassium fertilization was insignificant on the dry weight of the fennel plants on Sekem farm in both seasons except at vegetative and flowering stages in the second season. Fertilization with potassium sulphate significantly increased the fennel dry weight by 9 % and 10 % compared with the dry weight of fennel plants fertilized with feldspar at vegetative and flowering stage respectively in the second season. It can be summarised that fertilization with potassium sulphate was effective in increasing fennel dry weight on both soils compared to fertilization with feldspar.

The effect of potassium sources on the fruit yield per plant was significant on Giza farm and insignificant on Sekem farm in both seasons. Plants fertilized with potassium sulphate significantly increased the fennel fruit yield per plant by 8 % compared with the yield of plants grown on the plots fertilized with feldspar on clay loam in both seasons (Fig. 3-3).

Table 31: Effect of different potassium sources on fennel dry weight (g $plant^{-1}$)

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Vegetative stage				
Feldspar	171 a	162 a	68 a	107 a
K_2SO_4 (CK)	181 b	192 b	69 a	117 b
Flowering stage				
Feldspar	223 a	225 a	260 a	165 a
K_2SO_4 (CK)	240 b	226 a	260 a	182 b
Maturity stage				
Feldspar	257 a	301 b	273 a	422 a
K_2SO_4 (CK)	259 a	276 a	280 a	389 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

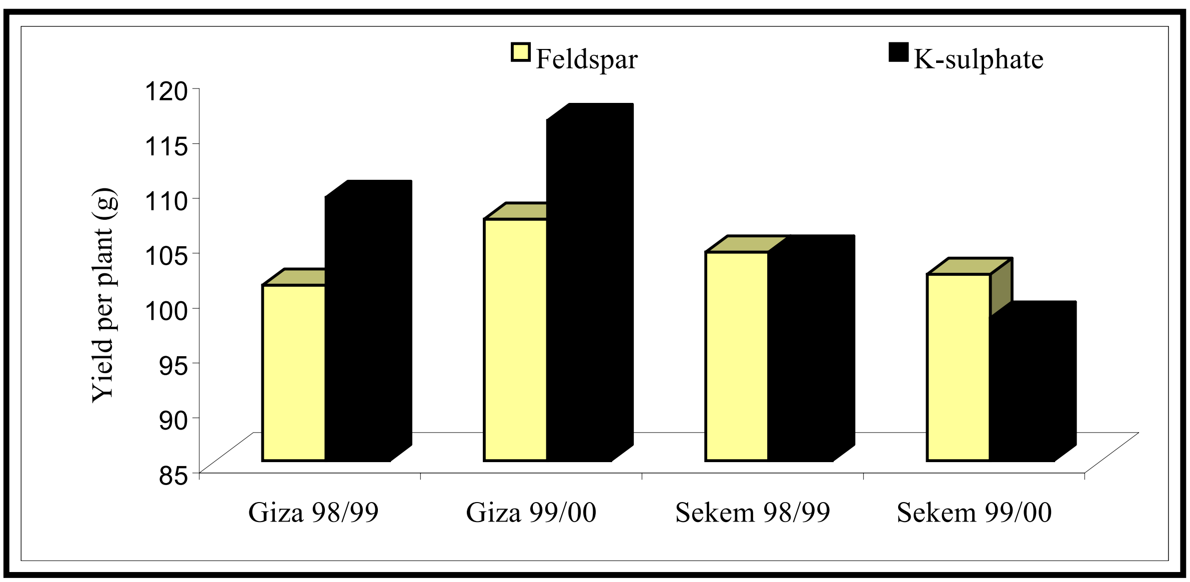

Fig. (3-3): Effect of different potassium sources on the fennel fruits yield (g $plant^{-1}$)

3.4 Effect of organic and inorganic fertilization on yield of fennel fruits and essential oil

3.4.1 Effect of different nitrogen sources

The effect of different nitrogen sources on fennel fruit yield (kg ha^{-1}) and essential oil yield (l $ha.^{-1}$) are shown in table 32. Results showed that ammonium nitrate gave the largest fruit yield (kg ha^{-1}) in both seasons and on both farms. Fertilization with compost in the Nile valley (Giza farm) resulted in 17 % and 7 % less yield than obtained after fertilization with ammonium nitrate, and 1 % and 12 % less on the sandy soil (Sekem farm) in both growing seasons respectively. Fertilization with chicken manure gave only 92 % of the yield of the plots fertilized with ammonium nitrate in both growing seasons in the Nile valley and 98 % and 85 % on Sekem farm in the first and second season, respectively. Fertilization with compost/*Azotobacter* increased the fruit yields by 14 % and 5 % compared with fertilization with compost alone in the Nile valley (Giza farm).

The yield of fennel essential oil was significantly affected by the different nitrogen sources on both farms in both seasons (table 32). The largest oil yield was obtained after fertilization with compost/*Azotobacter* followed by ammonium nitrate, chicken manure and compost alone gave the lowest in the first season in the Nile valley. While in the second season, fertilization with ammonium nitrate gave the largest oil yield followed by compost/*Azotobacter*, chicken manure and compost alone gave the lowest. On sandy soil (Sekem farm) fertilization with ammonium nitrate gave the largest oil yield followed by compost alone in the first season and compost/*Azotobacter* in the second season, while chicken manure gave the lowest oil yield in both seasons. In the case of nitrogen organic sources compost alone or compost/*Azotobacter* were more effective in increasing oil yield on the sandy soil (Sekem farm) compared with chicken manure. Fertilization with chicken manure or compost/*Azotobacter* were more effective in increasing fennel essential oil yield than did compost alone in the Nile valley (Giza farm). The yield of fennel fruits and essential oil were not substantially increased due to fertilization with compost/*Azotobacter* in the first season on the sandy soil (Sekem farm) but increased respectively by 13 % and 16 % in the second season compared with the yields of the plots fertilized with compost alone.

Table 32: Effect of different nitrogen sources on yield of fennel fruits and essential oil

Treatments	Fruits yield (kg ha^{-1})		Essential oil yield (l ha^{-1})	
	1998/1999	1999/2000	1998/1999	1999/2000
Giza farm				
Compost	2829 a	3152 bc	64 a	80 ab
Chicken manure	3125 ab	3079 a	72 b	73 a
Compost/Azotob.	3309 b	3295 b	81 c	82 b
Amm. nitrate (CK)	3389 c	3357 c	78 c	86 c
Sekem farm				
Compost	3161 ab	2606 a	69 b	68 a
Chicken manure	3099 ab	2803 a	62 a	67 a
Compost/Azotob.	2988 a	3007 ab	60 a	81 b
Amm. nitrate (CK)	3146 b	3304 b	71 b	86 b

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

3.4.2 Effect of different phosphorus sources

The effect of different phosphorus sources was significant on the yield of fennel fruits and essential oil in both seasons and on both soils (table 33). Fertilization with superphosphate gave the largest yield of fennel fruits (kg ha^{-1}) and essential oil yield (l ha^{-1}) followed by rock-P/S and rock-P alone gave the lowest yields in the first season on both farms. In the second season the largest yields were obtained after fertilization with rock-P/S on Giza farm and rock-P alone on Sekem farm while superphosphate gave the lowest yields.

Table 33: Effect of different phosphorus sources on yield of fennel fruits and essential oil

Treatments	Fruits yield (kg ha^{-1})		Essential oil yield (l ha^{-1})	
	1998/1999	1999/2000	1998/1999	1999/2000
Giza farm				
Rock-P	3102 a	3213 ab	72 a	80 b
Rock-P/S	3026 a	3274 b	72 a	84 c
Super-P (control)	3299 b	3116 a	77 b	74 a
Sekem farm				
Rock-P	2994 a	3089 b	66 b	83 b
Rock-P/S	3117 ab	2958 ab	63 a	73 a
Super-P (control)	3224 b	2744 a	68 b	69 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

3.4.3 Effect of different potassium sources

The effect of different potassium sources on the yield of fennel fruits and essential oil was significant in the Nile valley (Giza farm) and insignificant on Sekem farm in both seasons (table 34). The fertilization with feldspar on Nile valley soil resulted in 7.5 % and 6.3 % less fruits yield and 18.5 % and 22.4 % less oil yield compared with potassium sulphate in the first and second seasons respectively.

Table 34 : Effect of different potassium sources on yield of fennel fruits and essential oil

Treatments	Fruits yield (kg ha^{-1})		Essential oil yield (l ha^{-1})	
	(1998/1999)	(1999/2000)	(1998/1999)	(1999/2000)
Giza farm				
Feldspar	3048 a	3122 a	71 a	76 a
K_2SO_4 (CK)	3279 b	3319 b	77 b	93 b
Sekem farm				
Feldspar	3099 a	2926 a	66 a	78 a
K_2SO_4 (CK)	3106 a	2934 a	67 a	73 a

Numbers with different characters are statistically different at the 5 % level by the Tukey test.

3.5 Effect of organic fertilization on essential oil constituents

The essential oil content and the components of fennel oil are qualitatively different between not only the different varieties of fennel: *vulgare* (bitter), *dulce* (sweet) and *azoricum* (florance) (Marotti et al. 1994) but also between the continental cultivars of bitter fennel (Masada, 1967, Massoud, 1992 and Braun and Franz, 1999). Therefore, in this study it was necessary to investigate the effect of different treatments on fennel essential oil content and the main components in the oil.

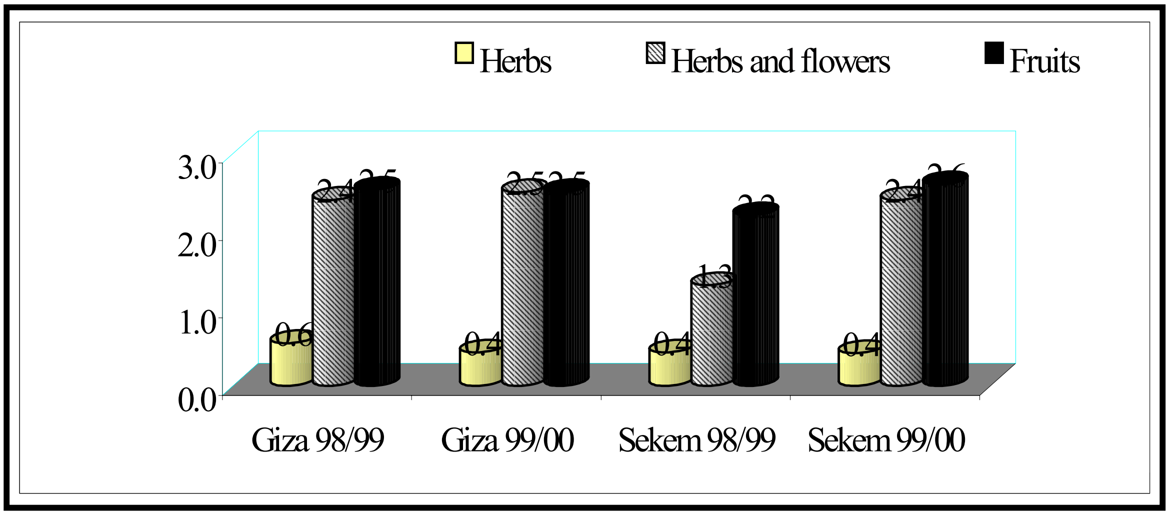

Fig. 3-4: Essential oil content (%) at different growth stages of fennel

The results indicate that fennel contained essential oil ranging from 0.43 % to 0.69 % (fennel herbs) at vegetative stage, 1.1 % to 2.6 % (fennel herbs and flowers) at flowering stage and 2 to 3 % (fennel fruits) at maturity stage (Fig. 3-4). Fennel essential oil content was not significantly affected by the different N, P and K sources at vegetative, flowering and maturity stages on both soils in both seasons.

GC-MS analysis of essential oil samples taken from the fennel herbs at vegetative stage, herbs and flowers at flowering stage and fruits at maturity stage in 1998/1999 and 1999/ 2000 seasons from plants receiving the different N, P and K sources indicated that limonene, fenchone, estragole and anethole are the main components of fennel essential oil. Other less important components constituted a relatively small content of the fennel essential oil in the two seasons. These results are in agreements with those obtained by Embong et al. (1977) and Braun and Franz (1999) who found that anethole, estragole, fenchone and limonene are the major constituents of fennel essential oil. They represent 99 % of herb oil and 93 % of the fruits oil.

3.5.1 Effect of nitrogen fertilization

Nitrogen fertilization in most cases did not significantly affect the composition of the essential oil. Starting with limonene which is separated first in GC column (fig. 3-5) it could be shown (table 35) that there have been only insignificant alterations due to the different nitrogen sources in the first season on Giza farm in the fennel herbs. On Sekem farm differences showed up in the composition of the herb's oil in respect to the limonene content. In the oil of the herb plus flowers from plants grown on Sekem farm significant differences have been found in the first and second seasons. No differences could be found in the fruit oil from plants grown on either farm in either seasons.

Plants grown on the plots fertilized with ammonium nitrate gave the highest limonene content followed by fertilization with compost/*Azotobacter*, compost alone and chicken manure gave the lowest limonene content. Fertilization with compost/*Azotobacter* increased limonene content by 40 % compared with application of compost alone. Limonene content was not affected significantly by nitrogen fertilization on sandy soil (Sekem farm) in both seasons except at vegetative stage in the first season and at flowering stages in both seasons. In the first season at fennel flowering stage, fertilization with compost and chicken manure increased significantly limonene content by 22 % compared with ammonium nitrate. While fertilization with compost/*Azotobacter* gave the same limonene content 36 % as observed after ammonium nitrate fertilization. In the second season, the highest limonene content in the fennel herb oil was obtained after fertilization with compost alone followed by chicken manure, compost/*Azotobacter* while fertilization with ammonium nitrate gave the lowest limonene content. The highest limonene content (47%) in fennel herb and flowers oil at flowering stage was obtained after fertilization with compost/*Azotobacter* followed by compost alone (43%), ammonium nitrate (41%) and fertilization with chicken manure gave the lowest limonene content (39 %). It can be summarised that limonene content in the fruits oil was not affected significantly by the different nitrogen sources in both seasons and on both soils.

Table 35: Effect of different nitrogen sources on limonene content in fennel essential oil (%)

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Herbs oil				
Compost	40 ab	42 a	41 a	51 b
Chicken manure	37 a	43 a	39 a	46 ab
Compost/Azotob.	56 ab	44 a	38 a	44 ab
Amm. nitrate (CK)	57 b	46 a	31 a	32 a
Herbs and flowers oil				
Compost	42 a	37 a	44 a	43 ab
Chicken manure	43 a	42 a	44 a	39 a
Compost/Azotob.	39 a	40 a	36 b	47 b
Amm. nitrate (CK)	42 a	41 a	36 b	41 ab
Fruits oil				
Compost	20 a	26 a	24 a	33 a
Chicken manure	22 a	28 a	23 a	33 a
Compost/Azotob.	23 a	30 a	22 a	32 a
Amm. nitrate (CK)	25 a	28 a	24 a	35 a

Numbers with different characters are statistically different at the 5% level by the Tukey test.

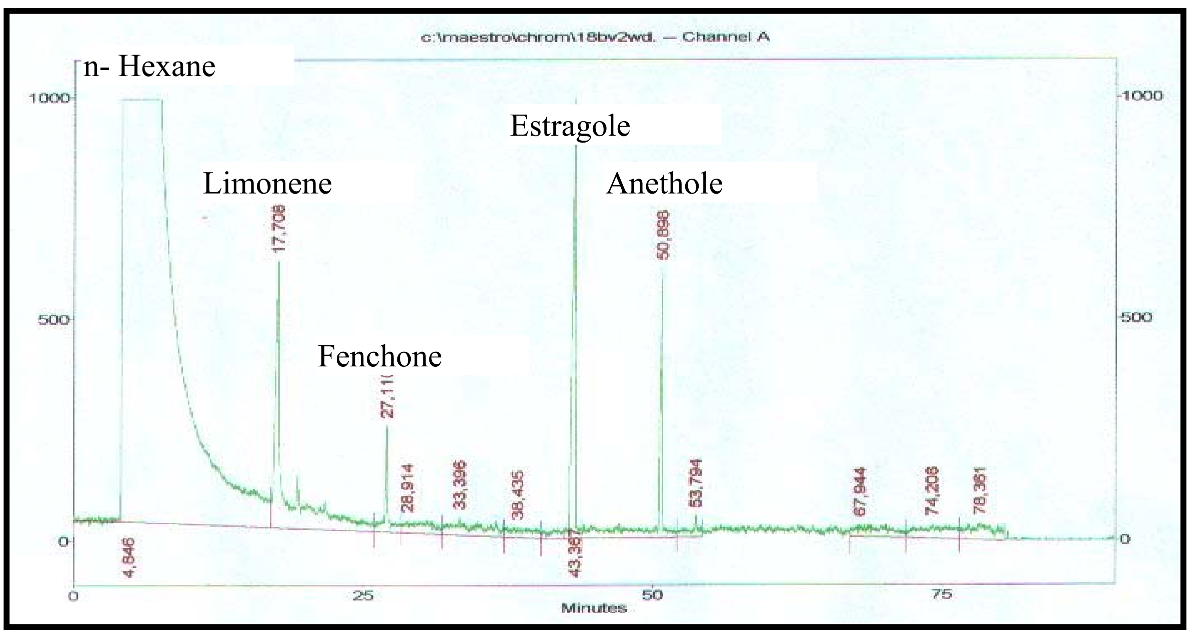

Fig. 3-5: GC chromatogram of the main components in the fennel essential oil

The effect of different nitrogen fertilization was insignificant on the fenchone content at all fennel growth stages in both seasons in the Nile valley (Giza farm) and in the second season on Sekem farm (table 36). At the vegetative and flowering stages, the highest fenchone content was obtained from fennel plants grown on the plots fertilized with chicken manure followed by compost/*Azotobacter* and ammonium nitrate, while the lowest content was obtained after fertilization with compost alone in the first season on Sekem farm. Fertilization with compost/*Azotobacter* gave the highest fenchone content at maturity stage followed by fertilization with compost alone, while fertilization with ammonium nitrate and chicken manure gave the lowest fenchone contents. Generally, it can be summarised that organic sources (compost and chicken manure) were more effective in increasing fenchone content than ammonium nitrate on both soils.

In both seasons the estragole content increased during plant development from the vegetative stage to flowering stage and the maximum content was obtained in the oil of fennel fruit at maturity stage. The estragole content was not significantly affected by fertilization with the different nitrogen sources on both soils in both seasons (table 37). The estragole content ranged from 25 % to 48 % at the vegetative stage, from 43 % to 53 % at flowering stage and from 57 % to 69 % at the maturity stage in both growing seasons on Giza farm. While estragole contents ranged from 32 % to 54 % at the vegetative stage, from 41 % to 49 % at the flowering stage and from 51 % to 68 % at the maturity stage in both growing seasons on Sekem farm.

Table 36: Effect of different nitrogen sources on fenchone content in fennel essential oil (%)

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Herbs oil				
Compost	18 a	7 a	3 a	10 a
Chicken manure	20 a	9 a	11 b	12 a
Compost/Azotob.	12 a	10 a	8 b	12 a
Amm. nitrate (CK)	11 a	10 a	5 a	10 a
Herbs and flowers oil				
Compost	8 a	8 a	8 a	6 a
Chicken manure	11 a	7 a	11 b	7 a
Compost/Azotob.	9 a	5 a	9 a	9 a
Amm. nitrate (CK)	8 a	8 a	8 a	8 a
Fruits oil				
Compost	7 a	10 a	8 ab	11 a
Chicken manure	8 a	9 a	6 a	11 a
Compost/Azotob.	7 a	11 a	9 b	12 a
Amm. nitrate (CK)	6 a	12 a	7 ab	10 a

Numbers with different characters are statistically different at the 5% level by the Tukey test

Anethole content obtained at all three growth stages of fennel in the first season and at maturity stage in the second season was not affected significantly by different nitrogen sources on Giza farm in both seasons except at maturity stage in the first season (table 38). Fertilization with chicken manure significantly increased anethole content by 50 % compared to ammonium nitrate fertilization. Similar anethole contents were obtained after fertilization with compost, compost/*Azotobacter* and ammonium nitrate at maturity stage in 1998/1999.

Table 37: Effect of different nitrogen sources on estragole content in fennel essential oil (%)

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Herbs oil				
Compost	32 a	47 a	41 a	35 a
Chicken manure	28 a	48 a	40 a	34 a
Compost/Azotob.	28 a	44 a	49 a	32 a
Amm. nitrate (CK)	25 a	43 a	54 a	41 a
Herbs and flowers oil				
Compost	48 a	51 a	48 a	47 a
Chicken manure	43 a	47 a	43 a	49 a
Compost/Azotob.	46 a	53 a	46 a	41 a
Amm. nitrate (CK)	49 a	49 a	49 a	49 a
Fruits oil				
Compost	69 a	60 a	66 a	51 a
Chicken manure	64 a	61 a	68 a	53 a
Compost/Azotob.	66 a	57 a	66 a	54 a
Amm. nitrate (CK)	65 a	58 a	66 a	53 a

Numbers with different characters are statistically different at the 5% level by the Tukey test.

On Sekem farm, anethole content was higher at the vegetative stage than at flowering and maturity stages in both seasons. Anethole content was significantly affected by different nitrogen sources only at vegetative and flowering stages of fennel in both seasons (table 38). It can be summarised that organic nitrogen sources; compost, compost/*Azotobacter* and chicken manure were more effective in increasing anethole content than ammonium nitrate.

Table 38: Effect of different nitrogen sources on anethole content in fennel essential oil (%)

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Herbs oil				
Compost	7 a	n.d	14 b	5 a
Chicken manure	5 a	n.d	9 ab	15 b
Compost/Azotob.	4 a	n.d	4 a	4 a
Amm. nitrate (CK)	7 a	n.d	10 ab	12 b
Herbs and flowers oil				
Compost	3 a	n.d	3 a	3.8 ab
Chicken manure	5 a	n.d	5 b	5.1 b
Compost/Azotob.	5 a	n.d	5 b	3.4 a
Amm. nitrate (CK)	5 a	n.d	5 b	2.3 a
Fruits oil				
Compost	3 a	3.0 a	2.4 a	3.2 a
Chicken manure	6 b	2.5 a	2.7 a	2.3 a
Compost/Azotob.	3 a	2.6 a	3.1 a	2.1 a
Amm. nitrate (CK)	3 a	2.7 a	3.0 a	2.2 a

Numbers with different characters are statistically different at the 5% level by the Tukey test.

3.5.2 Effect of phosphorous fertilization

The effect of different phosphorus sources was insignificant on the limonene content at all the three growth stages of fennel in both seasons and on both farms except at the vegetative stage on Sekem farm in the second season (table 39). Fertilization with rock-P decreased significantly the limonene content by 27% compared with that obtained after fertilization with superphosphate. Application of elemental sulphur increased the limonene content by 24 % and 19 % at the vegetative stage in the first and second season respectively.

Generally the limonene content was higher in the essential oil extracted from herbs at vegetative stage and from herbs and flowers at flowering stage than in the oil extracted from fruits at the fennel maturity stage. Limonene content in fennel essential oil in the Nile valley (Giza farm) ranged from 44 % to 50 %, from 39 % to 44 % and from 22 % to 23 % in the first season at vegetative, flowering and maturity stages respectively, while in the second season these values ranged from 39 % to 49 %, from 39 % to 43 % and from 27 % to 29 % (table 39).

It can be summarised that the different phosphorus sources had no significant effect on the limonene content in fennel fruit oil in both seasons and on both soils.

Table 39: Effect of different phosphorus sources on limonene content in fennel essential oil (%)

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Herbs oil				
Rock-P	44 a	39 a	35 ab	36 a
Rock-P/S	48 a	49 a	46 b	44 b
Super-P (control)	50 a	44 a	31 a	49 b
Herbs and flowers oil				
Rock-P	39 a	39 a	40 a	45 a
Rock-P/S	42 a	43 a	41 a	41 a
Super-P (control)	44 a	39 a	41 a	42 a
Fruits oil				
Rock-P	22 a	29 a	22 a	35 a
Rock-P/S	22 a	28 a	25 a	33 a
Super-P (control)	23 a	27 a	23 a	32 a

Numbers with different characters are statistically different at the 5% level by the Tukey test.

The effect of different phosphorous sources on fenchone content in the fennel oil at different growth stages was insignificant on both soils in both seasons except at flowering stage on Giza farm and at vegetative and maturity stages in the second season (table 40). Generally fertilization with superphosphate and rock-P/S were more effective than rock-P alone in increasing the fenchone content.

Table 40: Effect of different phosphorus sources on fenchone content in fennel essential oil (%)

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Herbs oil				
Rock-P	15 a	10 a	6 a	9 a
Rock-P/S	16 a	8 a	7 a	14 b
Super-P (control)	15 a	8 a	8 a	9 a
Herbs and flowers oil				
Rock-P	9 a	7 b	8 a	9 a
Rock-P/S	10 a	8 b	7 a	8 a
Super-P (control)	8 a	5 a	9 a	7 a
Fruits oil				
Rock-P	6.2 a	10 a	7 a	10 a
Rock-P/S	7.5 a	11 a	7 a	10 a
Super-P (control)	6.7 a	11 a	8 a	13 a

Numbers with different characters are statistically different at the 5% level by the Tukey test.

Table 41: Effect of different phosphorus sources on estragole content in fennel essential oil (%)

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Herbs oil				
Rock-P	30 a	51 a	49 b	34 a
Rock-P/S	29 a	40 a	39 a	39 a
Super-P (control)	25 a	46 a	50 b	34 a
Herbs and flowers oil				
Rock-P	49 a	50 a	50 a	45 a
Rock-P/S	44 a	46 a	50 a	41 a
Super-P (control)	46 a	53 a	46 a	42 a
Fruits oil				
Rock-P	67 a	58 a	68 a	35 a
Rock-P/S	65 a	59 a	65 a	33 a
Super-P (control)	66 a	60 a	66 a	32 a

Numbers with different characters are statistically different at the 5% level by the Tukey test.

Phosphorous sources did not affect the estragole content in the fennel essential oil at all three stages of fennel growth on Giza farm and Sekem farm in both seasons except at vegetative stage on Sekem farm in the first season (table 41). Fertilization with rock-P/S significantly decreased estragole content by 22 % compared with plants grown on plots fertilized with rock-P alone or with superphosphate.

The anethole content in the fennel oil was affected significantly by different phosphorous sources on Giza farm at vegetative and flowering stage in the first season (table 42). The essential oil of fennel plants grown on the plots fertilized with chemical fertilizer (superphosphate) contained the highest anethole content followed by plants fertilized with rock-P/S and the lowest content obtained in the plants fertilized with rock P alone in all three growth stages of fennel in the first season. While anethole obtained from fruits at the maturity stage in the second season contained the highest anethole content after fertilization with rock-P alone followed by rock-P/S, fertilization with superphosphate gave the lowest anethole content.

On Sekem farm, the anethole content was insignificantly affected by different phosphorous sources in both seasons except at the flowering stage in the first season and the vegetative stage in the second season (table 42). Fertilization with superphosphate significantly increased the anethole content by 40 % and 36% at the flowering stage in the first season compared with application of rock-P alone and rock-P/S respectively. The increments were 53 % and 38 % at the vegetative stage in the second season.

It can be summarised that fertilization with rock-P/S or superphosphate were more effective in increasing the anethole content than fertilization with rock-P alone on both types of soils.

Table 42: Effect of different phosphorus sources on anethole content in fennel essential oil (%)

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Herbs oil				
Rock-P	6 a	n.d	9 a	6 a
Rock-P/S	8 a	n.d	7 a	8 a
Super-P (control)	11 b	n.d	11 a	13 b
Herbs and flowers oil				
Rock-P	3 a	n.d	3 a	3
Rock-P/S	5 ab	n.d	3 a	4
Super-P (control)	6 b	n.d	5 b	4
Fruits oil				
Rock-P	4.0 a	2.3 b	2.7 a	2.6 a
Rock-P/S	3.3 a	2.2 ab	2.7 a	2.4 a
Super-P (control)	4.2 a	2.0 a	2.8 a	2.2 a

Numbers with different characters are statistically different at the 5% level by the Tukey test.

3.5.3 Effect of potassium fertilization

The effect of different potassium sources was insignificant at all the three growth stages of fennel on both soils in both seasons except at the flowering stage on Giza farm in the first season (table 43). Fertilization with feldspar significantly decreased limonene content by 17 % compared with the content of oil extracted from plants grown on plots fertilized with potassium sulphate.

Table 43: Effect of different potassium sources on limonene content in fennel essential oil (%)

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Herbs oil				
Feldspar	45 a	46 a	38 a	40 a
Potass. sulphate (CK)	41 a	41 a	37 a	46 a
Herbs and flowers oil				
Feldspar	38 a	40 a	42 a	42 a
Potass. sulphate (CK)	46 b	41 a	39 a	43 a
Fruits oil				
Feldspar	22 a	27 a	23 a	33 a
Potass. sulphate (CK)	23 a	29 a	24 a	34 a

Numbers with different characters are statistically different at the 5% level by the Tukey test.

Potassium fertilization on Giza farm had a significant effect on fenchone content in the fennel essential oil only at the vegetative and the maturity stages in the first season (table 44). At the vegetative stage in 1998/1999 fertilization with feldspar significantly decreased the fenchone content by 27 % compared with the oil extracted from the plants grown on the plots fertilized with potassium sulphate. While fertilization with feldspar increased the fenchone content significantly by 19 % and insignificantly by 10 % compared with the essential oil extracted from fruits of plants grown on plots fertilized with potassium sulphate in the first and second season respectively. On Sekem farm fenchone content was not affected significantly by potassium fertilization at all fennel growth stages in both seasons except at the maturity stage in the first season (table 44). Fertilization with feldspar significantly increased the fenchone content in the fennel oil by 20 % compared with the potassium sulphate fertilization.

Table 44: Effect of different potassium sources on fenchone content in fennel essential oil (%)

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Herbs oil				
Feldspar	13 a	8.6 a	6.8 a	10 a
Potass. sulphate (CK)	18 b	9.3 a	6.6 a	12 a
Herbs and flowers oil				
Feldspar	9 a	7 a	7.3 a	7.5 a
Potass. sulphate (CK)	9 a	7 a	8.2 a	8.3 a
Fruits oil				
Feldspar	7.4 b	11 a	8.4 b	10 a
Potass. sulphate (CK)	6.2 a	10 a	7.0 a	12 a

Numbers with different characters are statistically different at the 5% level by the Tukey test.

Table 45: Effect of different potassium sources on estragole content in fennel essential oil (%)

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Herbs oil				
Feldspar	28 a	45 a	42 a	35 a
Potass. sulphate (CK)	28 a	46 a	50 a	36 a
Herbs and flowers oil				
Feldspar	48 a	48 a	47 a	48 a
Potass. sulphate (CK)	45 a	51 a	49 a	45 a
Fruits oil				
Feldspar	65 a	58 a	66 a	54 a
Potass. sulphate (CK)	67 a	59 a	67 a	52 a

Numbers with different characters are statistically different at the 5% level by the Tukey test.

The estragole content was not significantly affected by different potassium sources at all the three growth stages of fennel in both seasons on both soils (table 45). The anethole content was higher in the fennel oil extracted from herbs and flowers than in the fennel oil extracted from fruits. Anethole like the estragole was not significantly affected by different potassium sources at all the three growth stages of fennel on both soils in both seasons except at maturity stage in the first season on Sekem farm (table 46). Fertilization with feldspar increased anethole content by 43 % compared with the anethole content in the fruits oil extracted from plants grown on the plots fertilized with potassium sulphate.

Table 46: Effect of different potassium sources on anethole content in fennel essential oil (%)

Treatments	Giza farm		Sekem farm	
	(1998/99)	(1999/00)	(1998/99)	(1999/00)
Herbs oil				
Feldspar	6 a	n.d.	7 a	9.6 a
Potass. sulphate (CK)	7 a	n.d.	9 a	8.3 a
Herbs and flowers oil				
Feldspar	4.2 a	n.d.	3 a	3.1 a
Potass. sulphate (CK)	4.9 a	n.d.	4 a	4.2 a
Fruits oil				
Feldspar	4.2 a	2.8 a	3.3 b	2.2 a
Potass. sulphate (CK)	3.5 a	2.1 a	2.3 a	2.7 a

Numbers with different characters are statistically different at the 5% level by the Tukey test.

4 DISCUSSION

The main objective of this study was to find out whether sufficient and high quality yields of the fennel crop can be produced without chemical fertilizers but only with the sources allowed by organic farming rules under Egyptian conditions. The extensive use of manufactured chemical fertilizers on the Nile valley soils has increased crops productivity but compromised quality especially for medicinal and aromatic plants which therefore are not acceptable for export. Coupled to this, most of the new reclaimed land in Egypt are sandy soils which are normally poor in essential plant nutrients. In the rural areas, organic fertilization plays an important role in agricultural productivity. Fennel an important medicinal plant grows well under Egyptian conditions and plays an important role in foreign exchange earnings. To investigate the effect of organic and inorganic sources of N, P and K on the yield of fennel fruits and essential oil, it was important to study the effect of different treatments on soil fertility parameters, total content of macro- and micro nutrients in the fennel herbs and fennel growth parameters at different physiological stages.

All organic fertilizers are complex in native and hence it is difficult to isolate the effects caused by the different components. Organic fertilizers are excellent sources of nutrients for crop production and improving physical and chemical properties of soil (Eghaball and Power, 1994). Many studies have shown that the fertilizing power of compost is due to its content of stabilized organic matter and due to the amount of nutritive elements contained therein (Bevacqua and Mellano, 1993). Warman, (1990) found that compost had an effect similar to commercial fertilizer to provide the same amount of total nitrogen, but could have released available nitrogen.

Most of research with chicken manure has been directed to its use as a nitrogen source with subsequent evaluation of mineralization and nitrification processes (Castellanos and Pratt, 1981, Chae and Tabatabai, 1986). Chicken manure may increase soil organic matter, exchangeable Mg^{+2} and K^{+} and available P (Bahango et. al. 1988). Shortal and Leibhardt, (1975) found that, chicken manure can also increase soil electrical conductivity to a level that may be detrimental to crops. Bahango et al. (1988) and Ohallorans et al. (1993) found that fertilization with chicken manure increased not only available nitrogen but also exchangeable potassium in the soil.

However, organic matter is not essential for plant growth, although it has been suggested that humic substances can have a direct effect on plant growth, assuming a hormonal action of humic substances (Varanini and Pinton, 1995). Soil organic matter is the component of mineral soils, that makes it possible for successful growth of most plants. Soil organic matter can increase water holding capacity and cation exchange capacity in sandy soil. It adds structure, stability and permeability to soils high in clay. For all soils organic matter is a source of nutrients, usually slow released as organic matter is decomposed. Compaction and many other soil problems are mainly due to loss of soil organic carbon. Soil organic matter supplies nutrients, it is a buffer against pH change, it protects against plant diseases, protects against heavy metal and salt toxicity, detoxifies pesticides and prevents their leaching, promotes microbial breakdown of toxic substances and supports micro-organisms that recycle nutrients and soil formation (Varanini and Pinton, 1995).

Compost has a similar effect as chemical fertilizer, providing the same amount of total nitrogen but could release less available nitrogen, giving the normal rate of mineralization (Ballif, 1990). Also Atta et al. (1999) found that no significant differences on fennel yield due to fertilization with inorganic and organic nitrogen sources. Same results have been found by El-Hady et al. (1991), Dahdoh and El-Hassanin (1993) and Dahdoh and El-Demerdashe (1994). On the other hand, Alghadban (1998) found that organic fertilization significantly increased the herb and essential oil yields of spearmint and marjoram compared with the recommended N, P and K fertilization for those plants. The addition of organic materials is a true reflection of (a) improving soil aggregation and increasing water stable aggregates (Mostafa, 1986), (b) increasing the soil water retention and water holding capacity (Gouda, 1984), (c) improving dynamic soil-water characteristics, i.e.: decreasing the downward water movement through infiltration (El-Tokhy, 1982) and its upward movement via evaporation (Ahmed, 1990) and (d) the contribution of organic matter to the nutritional elements in soils. The latter contribution include: (1) decrease in soil pH which leads to solubilization of nutrients and increases nutrient availability and supply (Salem, 1986), (2) organic matter as a complexing agent, thus minimises the loss of nutrients by leaching (Balba, 1973) and (3) stimulates bio-degradation through increasing the population and activities of micro-organisms in the soil (Amara and Dahdoh, 1995).

Nitrogen economy and maintenance of soil fertility through bacterial inoculants has immense important in the present day agriculture. Several reports emphasised the role of a symbiotic N-fixing bacteria (*Azotobacter chroococum*) in increasing yields and improving nutrients uptake by field crops (Zeid, 1992).

Azotobacter can affect plant growth directly, either by the nitrogen it fixes (Zaid, 1992, and Madkour et al. 1987), or through growth promoting substances (indol-3-acetic acid, gibberellins and cytokinins (Barea and Brown, 1974; Pareek et al. 1996 and Zahir et al. 1997), or indirectly by change in the microflora of the rhizospher (Barea and Brown, 1974).

Other components which influence plant growth in a positive way are multi-components fertilizers like the phosphorus sources (rock-P, rock-P/S and calcium superphosphate) because they contain not only P but also Ca, Mg and micro-nutrients. Also application of elemental sulphur with rockphosphate (rock-P/S) can affect plant growth directly, either by the macro-nutrients: P, Ca, S and the micro-nutrients, or indirectly by slightly change in soil pH which affect all the plant nutrients in the soil solution (El-Leboudi and Omer, 1975). Also Fenn et al. (1987) revealed that, incremental S additions increased the water extractable Ca, Mg and P from the soil. On the other hand, Schnug (1990) recommend the use of S fertilization not only for increasing yield and quality of vegetables but also protective against pests and diseases.

Although feldspar is an important source of K, its slow dissolution rates in poor correlation between the amount of feldspar in a soil and the amount of K absorbed by plants (Foth and Ellis, 1996). On the other hand, Ciompi (1997) found no significant differences in K content of plants between K supply in solution or as feldspar. Chemical analysis of feldspar revealed that feldspar contains not only K but also Fe, Mn, Zn and Cu (table 5). Also potassium sulphate is a combined fertilizer because it contains not only K but also S. Also not only potassium sources contained potassium but also compost and chicken manure contained potassium (table 4). So it is not possible to say what the causing factors for effects.

Generally organic fertilization gave similar effects on macro- and micronutrients in the soils as observed after chemical fertilization as control. In some cases fertilization with compost, chicken manure and compost/*Azotobacter* gave higher DTPA extractable Fe, Mn, Zn and Cu than fertilization with ammonium nitrate. These results are in agreement with those obtained by Eghaball and Power (1994). They found that organic fertilizers were excellent sources of nutrients for crop production and for improving physical and chemical properties of the soil.

The increase in available phosphorus and potassium in the plots fertilized with compost and chicken manure compared with ammonium nitrate may be a result of higher contents of P and K in the compost and chicken manure. Although compost and chicken manure contain P and K, the plots fertilized with superphosphate and potassium sulphate were more effective in increasing available P and available K respectively. Fertilization with superphosphate significantly increased the available phosphorus compared with rock phosphate alone and rock-P/S. An increase in the availability of phosphate to plants when phosphate rocks are granulated with sulphur and applied to soil has been reported by many researchers (Rajan, 1983 and Kumar et al. 1992). On the other hand fertilization with rock-P/S was more effective in increasing the availability of P and micronutrients in the soil compared with rock-P alone.

Although no significant differences were observed between fertilization with superphosphate and rock-P/S on DTPA extractable Fe in the second soil sample in the first season. In the second season, DTPA extractable soil Fe decreased significantly by 4.5 % and 6 % compared with superphosphate after fertilization with rock P and rock-P/S respectively. These results may be due to the chemical reaction with rock phosphate which reduced the solubility of Fe (Kumer et al. 1992). The superiority of rock-P/S compared with rock-P alone in increasing macro- and micronutrients in both soils may be due to the oxidation of sulphur to sulphuric acid by *Thiobacillus spp.* bacteria, the decreasing soil pH and the increased availability of nutrients (Rajan, 1987, Kumer et al. 1992 and El-Leboudi and Omer, 1975). DTPA extractable soil Cu was not affected by the different phosphorus sources in both seasons in clay loam soil. These results may be due to the high total Cu content in the Egyptian soils from 18 to 100 mg kg^{-1} (Tahoun et al. 1999 and Ghada, 2000). The slight decrease of soil pH in the plots fertilized with feldspar compared to those fertilized with potassium sulphate may be caused an increase in the availability of plant nutrients to give similar DTPA Fe, Mn, Zn and Cu as potassium sulphate (control). No significant differences were observed on total content of macro- and micronutrients in the fennel herb due to fertilization with different sources (organic and inorganic) of N, P and K. This result indicates that organic fertilization was sufficient to supply similar macro- and micro nutrients in the soils to uptake by fennel plants or fennel did not respond to supplementary N, P and K treatments. These results are in agreement with those obtained with Buntain and Chung, (1994) and Damato et al. (1994). On the other hand many results indicated that fennel responded to the high rate of N, P and K from the different sources

(Bhati et al. 1988, Ahmed et al. 1988, Hussein and Abou El-Magd, 1991 and Sharma et al. 1995).

4.1 Fennel growth under organic fertilization

Generally the largest fennel growth was obtained after fertilization with ammonium nitrate on both soils while compost alone gave the lowest. In the case of organic nitrogen sources compost/*Azotobacter* and chicken manure were more effective in increasing the fennel growth on both soils compared with compost alone. Although the different nitrogen sources did not significantly affect the total content of macro- and micronutrients in the fennel herb, the growth parameters (plant height, branches per plant and fennel dry weight) at vegetative, flowering and maturity stages and the fennel fruit yield per plant at maturity stage were affected significantly by the different nitrogen sources (tables 23, 24 and 25 and figure 3-1). In many cases organic sources especially compost/*Azotobacter* and chicken manure gave similar growth as obtained after fertilization with ammonium nitrate. It can be concluded that fertilization with ammonium nitrate was more effective in increasing the fennel growth than organic fertilization. El-Ashry (1992) indicated that ammonium nitrate is one of the most common forms of solid nitrogen fertilizers. It is readily available for uptake by plants due to nitrate ions which are readily soluble in the soil solution and is not adsorbed on the cation-exchange complex. Ammonium ions also can be adsorbed on the adsorption positions of soil particles. It is greatly subjected to no losses through leaching as well as denitrification under anaerobic soil conditions and its leaching through the water drainage (Osman, 1985). Also Hussein, (1995) found that the maximum value of plant height for coriander and dill was obtained by application of nitrogen fertilizer in the form of ammonium nitrate. The increase of available nutrients in the plots fertilized with ammonium nitrate and compost/*Azotobacter* probably increased the fennel growth.

In the case of organic sources compost/*Azotobacter* was more effective than compost alone or chicken manure in increasing fennel growth on both soils. The superiority of *Azotobacter* may be due to not only its ability to fix nitrogen but also through growth promoting substances (indol-3-acetic acid, gibberellins and cytokinins (Pareek et al. 1996 and Zahir et al. 1997), or indirectly by a change in the microflora of the rhizospher (Barea and Brown, 1974). Also El-Kassas (1999) found that the highest number of branches, plant height and yield of fennel seed was obtained with plants grown on soils fertilized with compost mixed with bacteria. Although several reports indicated that fennel growth was not affected by nitrogen fertilization (Buntain and Chung, 1994 and Damato et al. 1994), several reports emphasize the role of a symbiotic nitrogen fixing bacteria in increasing yields and improving nutrient uptake by field crops (Zapater, 1982). El-Shanshoury et al. (1989) also found that the innoculation with *Azotobacter* alone increased the root depth, shoot height, fresh and dry weight of roots and shoots significantly. The superiority of chicken manure over compost alone my be due to the ability of chicken manure to increase soil organic matter, exchangeable Mg^{+2}, exchangeable K^{+} and available phosphorus (Castellanos and Pratt, 1981 and Chae and Tabatabai, 1986).

Generally the tallest fennel plants, the highest number of branches per plant, and the largest dry weight at different growth stage of fennel and fennel fruits per plant at maturity stage were obtained after fertilization with superphosphate in both seasons and on both soils. Also the different phosphorus source did not significantly affect the macro- and micronutrients in the fennel herb and in many cases fennel growth characters were significantly affected by phosphorus fertilization. In the case of P uptake, rockphosphate mixed with elemental S tended to show its superiority over superphosphate. Although the chemical fertilizer (superphosphate) was effective in increasing the fennel growth characters, fertilization with rock-P/S not only gave similar results as obtained after fertilization with superphosphate but also increased the fennel growth characters over chemical fertilization and rock-P alone. Similar results were obtained into other plants by Khalaf and Taha (1988) into garlic, by Hilal and Korkor (1993) into cucumber and by Sharma et al. (1995) into camellia. These results may be due to not only the high levels of available phosphorus and DTPA extractable Fe, Mn, Zn and Cu in the plots fertilized with rock-P/S compared with those fertilized with superphosphate and also sulphur as essential macronutrient. These results are in agreement with those obtained by El-Leboudi and Omer (1975). They found that sulphur application decreased soil pH. Similar observations were reported by Pareek et al. (1987). Also Schnug (1990) recommend the sulphur fertilization for the enhancement of quality of vegetables and emphasized the requirement of sulphur compounds for resistance against pests and diseases. On the other hand, Sastry et al. (1997) found that, rock phosphate was more effective as single superphosphate in improving flower yields of pyrethrum in the second year after planting. Dwivedi et al. (1990) found that a greater availability and higher labile pool of P is causing from superphosphate than from rock phosphate under neutral soil conditions.

Although rock phosphate is quite effective in acid soils, it is considered as a poor phosphorus source in the neutral and alkaline soils (Cooke, 1997; Randhawa et al. 1981 and Goraya et al. 1984). Bhati et al. (1988) found that the effect of phosphorus fertilization on all fennel growth characters were not significant during the three years of the study. The high concentration of available phosphorus in the plots receiving rockphosphate and rock-P/S may have not only resulted from rockphosphate but also from the other organic fertilizers (chicken manure contained 2.9 % total phosphorus). These results are in agreement with those obtained by Naik et al. (1993). They found that single superphosphate significantly increased the plant growth characters over fertilization with rockphosphate alone or when in combination with phosphorus solubilizing bacteria.

Generally potassium fertilization had no significant effects on fennel growth characters during the three fennel periods of its growing cycle. These results may be due to the different potassium sources giving similar macro- and micronutrients in the fennel herbs. These results are in agreement with those obtained by Ciompi et al. (1997) who found no significant differences in potassium content of plants between potassium supply in solution or as feldspar in either N-sufficient or N-deficient plants. But in some cases, chemical fertilizer (potassium sulphate) was more effective in increasing fennel growth characters on both soils than did natural potassium source (feldspar). These results may be due to the available potassium being slightly higher in the plots fertilized with potassium sulphate than in those fertilized with feldspar. Also the superiority of potassium sulphate may be due to its higher availability to plants than feldspar, which requires further processing (Sparks and Huang, 1985). The relation between potassium feldspar and the readily exchangeable potassium, indicates that feldspar contributed little to available potassium in the soil (Alafifi, 1996). Bakken et al. (1997) also found that application of potassium as K-feldspar was nearly unavailable to the plants.

4.2 Fennel yield under organic fertilization

The effect of different nitrogen sources was significant on the fennel fruit yields and essential oil yield (table 32). Generally fertilization with ammonium nitrate gave the largest fennel fruit yields and yields of essential oil followed by compost/*Azotobacter*, while compost alone gave the lowest in both seasons and on both soils. Fertilization with compost/*Azotobacter* increased the fruit yields by 14 % and 5 % compared with fertilization with compost alone in the Nile valley (Giza farm). Although fertilization with compost/*Azotobacter* was not effective in increasing the yield of fennel fruits and essential oil in the first season on sandy soil (Sekem farm), the yield of fennel fruits and essential oil increased by 13 % and 16 % compared with the yield of the plots fertilized with compost alone, respectively. In many cases no significant differences were observed on the yield of fennel fruits and essential oil due to fertilization with chemical fertilizer (ammonium nitrate) and organic sources: compost, compost/*Azotobacter* and chicken manure. The superiority of organic fertilization in increasing the yield of fennel fruits and essential oil compared with chemical fertilizer (ammonium nitrate) may be a result of organic fertilization giving similar amounts of plant nutrients to the soils. Resulting from this organic fertilization similar amounts of nutrient contents in the fennel herb, similar fennel growth and similar essential oil contents as observed after ammonium nitrate fertilization has been found.

Although the different phosphorus sources did not affect the macro- and micronutrients in the fennel, the effect of different phosphorus sources was significant on the yield of fennel fruits and essential oil in both seasons and on both soils (table 33). Generally fertilization with superphosphate gave the largest yields of fennel fruit and essential oil followed by rock-P/S and rock-P alone gave the lowest yield on both soils in the first season. While in the second season, the largest yields were obtained after fertilization with rock-P/S on Giza farm and rock-P alone on Sekem farm and superphosphate gave the lowest. The superiority of natural phosphorus sources (rock-P and rock-P/S) compared with superphosphate (chemical fertilizer) in increasing the yield of fennel fruits and essential oil may be in many cases a result of similar nutrients in the soil, similar nutrient content in the fennel herbs and similar fennel growth on both soils as observed after chemical fertilization. Randhawa et al. (1981) and Khan et al. (1992) revealed that phosphorous fertilization did not affect the yield of fennel fruits and essential oil.

Although potassium sources did not affect the macro- and micronutrients in the soils and in the fennel herbs, the effect of different potassium sources on the yield of fennel fruits and essential oil was significant on Nile valley (Giza farm) and insignificant on Sekem farm in both seasons (table 34). The increase in the yields of fennel fruit and essential oil in the plots fertilized with potassium sulphate may be a result of increased the fennel growth (dry weight and fruits yield per plant) in the plots fertilized with potassium sulphate compared with those fertilized with feldspar. Alafifi (1996) found that a negative relation between K-feldspar and the ready exchangeable K, indicating that K-feldspar contributed little to available K in soil. Also

Bakken et al. (1997) stated that application of potassium as feldspar was nearly unavailable to plants. While Barman et al. (1992) found that organic acids such as oxalic, citric, salicylic and glycine dissolve minerals by a combined action of complexation and acid attack. Feldspar tended to show its superiority over potassium sulphate under these conditions, the observed yield effects might be due to improved sulphur supply by the sulphate.

4.3 Essential oil quality of fennel under organic fertilization

In the case of fennel essential oil content, fennel did not respond to supplementary nitrogen, phosphorus and potassium treatments in both seasons and on both soils. This result indicates that the level of nutrients in the soil was sufficient. Because the different natural sources of N, P and K gave similar macro- and micronutrients in the fennel herbs and similar essential oil content was obtained after fertilization with natural sources compared with chemical fertilization of N, P and K (ammonium nitrate, superphosphate and potassium sulphate). These results are in agreement with those obtained by Buntain and Chung (1994). Also Randhawa et al. (1981) and Khan et al. (1992) revealed that, the application of nitrogen and phosphorous did not affect the oil content in the fennel fruits. On the other hand, Correa et al. (1999) found that, organic and inorganic fertilization had no effect on the content of the essential oil of chamomile. While Ahmed et al. (1988) revealed that, the fennel plants fertilized with 100 kg h^{-1} N gave 5 % less essential oil content than did the fertilization with 50 kg h^{-1} N. In contrast to this, Abdallah et al. (1978) reported that the fennel oil percentage increased with increasing nitrogen.

GC-MS analyses of essential oil samples taken from the fennel herbs at vegetative stage, herbs and flowers at flowering stage and fruits at maturity stage in 1998/1999 and 1999/ 2000 seasons from plant receiving the different N, P and K sources, indicated that limonene, fenchone, estragole and anethole are the main components of fennel essential oil. Other less important components constituted a relatively small percentage of the fennel essential oil in the two seasons. These results are in agreement with those obtained by Embong et al. (1977), Singh and Mahey (1994) and Braun and Franz (1999). They found that these volatiles are the major constituents of fennel essential oil representing 99 % of herb oil and 93 % of the total fruits oil.

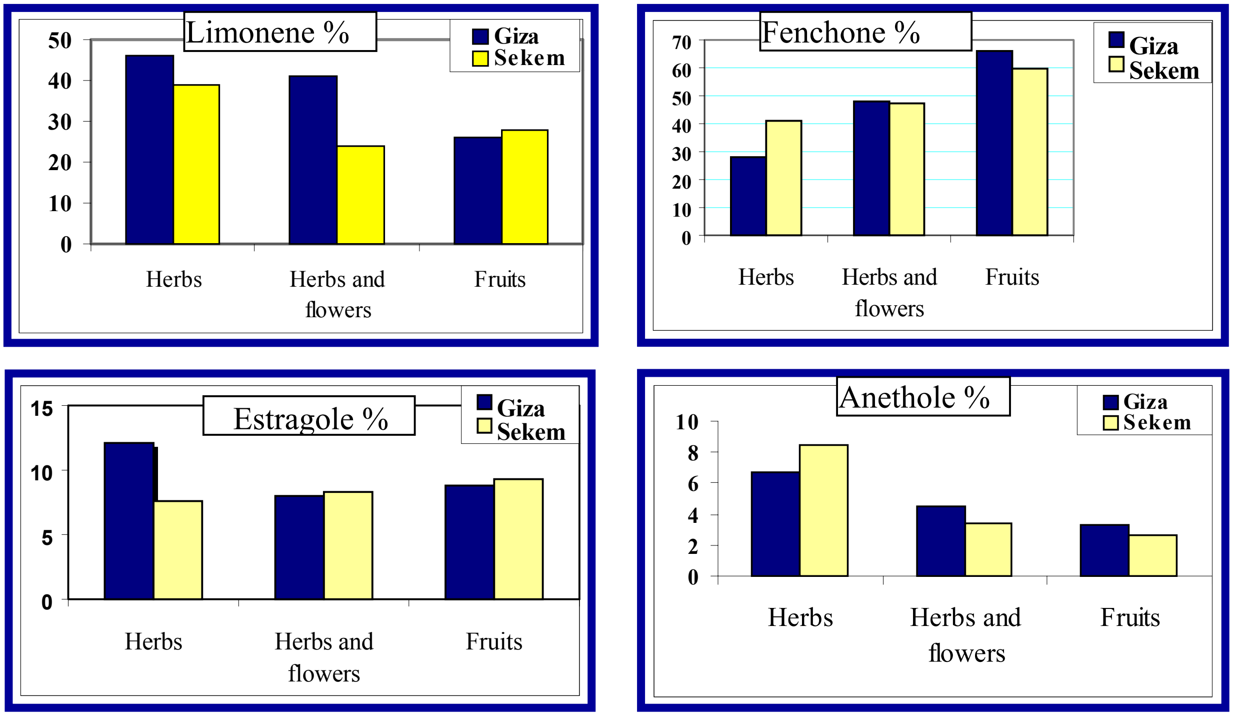

Fig. 4-1: Differences in the composition of the oil from different plant parts.

The differences in the composition of the oil from different plant parts are larger than the differences in the composition of the oil from plants grown on the two different soil types: Giza and Sekem farm (Fig. 4-1). This means, oil quality did not change on both different types of soil and sandy soil is suitable for fennel agriculture under Egyptian conditions.

The limonene content was higher at vegetative stage (from 40 % to 57 % and 31 % to 51 %) and flowering stages (39 % to 43 % and 36 % to 47 %) than at maturity stage (20 % to 30 % and 22 % to 35 %) of fennel plants cultivated on Nile valley and Sekem farm respectively. These percentages are in agreement with those obtained by Charles et al. (1993). Also Marotti et al. (1994) revealed that bitter fennel oil contains 26 % to 47 % limonene. On the other hand, Badoc et al. (1994) found that the fruits essential oil of fennel cultivated in north France contains from 36 % to 56 % limonene. The fenchone contents are similar as observed by many investigators; Marotti et al. (1994) 5 % to 9 %, Badoc et al. (1994) 1.9 % to 3.5 %, Arslan et al. (1989) from 1.5 % to 14 % and Venskutonis et al. (1996) from 3.6 % to 11 %. The estragole content increased from vegetative stage, through the flowering stage and maximum content was obtained at the fennel maturity stage in both seasons. The estragole content was similar with those obtained by Masada (1976) and Massoud (1992). Other varieties contain less estragole than those obtained in this study (Baser et al. 1997). The anethole content of fruit oil was lower than those obtained by Massoud (1992) who found 40 % in Egyptian fennel cultivar. But the fennel cultivar under investigation in this study gave similar anethole content as reported by Braun and Franz (1999) in Italian varieties.

For medicinal purposes only the fennel fruits oil of variety *vulgare* (bitter fennel) is accepted by the European pharmacopoeia (Braun and Franz, 1999). Because the fennel fruits oil components (limonene, fenchone, estragole and anethole) were not significantly affected by the different treatments of N, P and K, it can be concluded that organic fertilization gave similar fennel fruit oil quality as observed after chemical fertilization. These results are in agreements with those obtained by Buntain and Chung (1994), who found no significant effect of nitrogen fertilization on any components in the fennel essential oil. While Desmarest (1978) found that a high rate of N reduced the anethole content, fennel did not respond to supplementary N, P and K treatments. This indicates that the levels of N, P and K in the soil were sufficient and organic fertilization was sufficient for the fennel yields and qualities produced under Egyptian conditions.

Because plants suffering from P deficiency are stunted with a limited root system and thin stems and frequently the development of the fruits. The formation of fruits and seeds is especially decreased in plants suffering from P deficiency. Thus not only low yields but also poor quality fruits and essential oils are obtained from P deficiency (Abou El-Magd and Hussein, 1992). Khan et al. (1992) found that fenchone content of fennel essential oil and fenchone yield were considerably increased by the higher P application. On the other hand the application of different phosphorus sources did not have any effect on fennel essential oil constituents (Ahmed et al., 1988). And the result indicated that no significant differences were observed on the main components of fennel fruits oil due to fertilization with superphosphate and rock-P/S. It can be recommended that rock-P/S can give similar fennel yield and essential oil quality.

Fennel did not respond to supplementary potassium treatments, because no significant differences were observed on available potassium in the soil and total content of K in the fennel herbs due to fertilization with different potassium sources. This indicates that the level of K was sufficient or potassium did not play any role in the main components content of fennel essential oil. The superiority of feldspar to increase fenchone content of fennel essential oil may be due to the fact that not only feldspar can release K at slower rates than soluble K fertilizers do (Bakken et al., 1997) but also feldspar contained Fe, Mn, Cu, Mn and Zn. On the other hand, Abdallah et al. (1978) found that potassium fertilization increased only the fennel oil components in the second season.

5 CONCLUSIONS

For medicinal purposes only the fennel fruits oil of variety *vulgare* (bitter fennel) is acceptable by the European pharmacopoeia (Braun and Franz, 1999). Generally the fennel fruit oil components (limonene, fenchone, estragole and anethole) were not significantly affected by the different treatments of N, P and K. Thus far it can be concluded that organic fertilization gave similar fennel fruit oil quality as observed after chemical fertilization. On the other hand, the differences in the composition of the oil from different plant parts are larger than the differences in the composition of the oil from plants grown on the two different soil types. This means, oil quality did not change on both different type of soils.

Table 47 : Relative yield under organic and inorganic fertilization

N sources	Giza farm		Sekem farm	
	Fruits (%)	Oil (%)	Fruits (%)	Oil (%)
Compost	89	89	88	87
Chicken manure	92	92	89	82
Compost/*Azotobacter*	98	93	99	89
Ammonium nitrate	100	100	100	100

It can be recommended that fennel (*Foeniculum vulgare* Mill) plants should be fertilized with compost/*Azotobacter* on both soils to get higher yields of fennel fruit and essential oil. In some cases fertilization with chicken manure gave higher yield than did fertilization with compost/*Azotobacter*. Thus chicken manure can be recommended for use although its limited by high costs in Egypt. In addition to this, the use of compost and *Azotobacter* are also often desirable because the fruit and oil yields resulting from organic fertilization are free of chemicals, therefore considered to be of superior quality, compared with the yield resulting from chemical fertilizer. Also organic products are usually sold at a much higher price.

Means of fennel yields fruit yield (kg ha^{-1}) and essential oil yield (l ha^{-1}) during the two successive seasons (1998/1999 and (1999/2000), indicated that fertilization with superphosphate gave the highest fruit and oil yields followed by rock-P/S and rockphosphate alone gave the lowest yields on clay loam soil (Giza farm). The opposite was true on sandy soil. It can be recommended that fennel (*Foeniculum vulgare* Mill.) plants should be fertilized with rockphosphate mixed with elemental sulphur in clay loam soil and rock-P alone in sandy soil under organic fertilization. The P release in both soils resulted from not only P fertilizers, rock-P and superphosphate but also from compost and chicken manure in this study. In the case of chemical fertilization; it can be recommended that fennel (*Foeniculum vulgare* Mill) plants should be fertilized with superphosphate at the rate of 40 kg ha^{-1} P in both clay loam and sandy soils to get higher yields of fruits and essential oil.

Fertilization with feldspar or potassium sulphate gave no significant differences in fruit yield (kg ha^{-1}) on sandy soil (Sekem farm) in both growing seasons. While fertilization with feldspar on clay loam soil (Giza farm) resulted in 7.5 % and 6.3 % less fruit yield than obtained after fertilization with potassium sulphate in the first and second seasons respectively. Potassium sources had insignificant effects on fennel essential oil yield on Sekem farm in both seasons. While fertilization with feldspar on clay loam soil resulted in 18.5 % and 22.4 % less of the fennel oil yield obtained after fertilization with potassium sulphate in the first and second season respectively. Feldspar tended to show its superiority over potassium sulphate under these conditions. The observed yield effects might be due to improved sulphur supply by the sulphate. It can be recommended that fennel (*Foeniculum vulgare* Mill.) plants should be fertilized with feldspar at the rate of 50 kg ha^{-1} K in both clay loam and sandy soil under organic fertilization to get higher fruit yields and better essential oil quality. Because the K release in both soils resulted from not only K sources, feldspar and potassium sulphate but also from compost and chicken manure in this study. Feldspar can not be recommended for fennel fertilization under chemical fertilization of fennel.

6 SUMMARY

The main objective of this study was to find out whether sufficient and high qualities of fennel yields can be produced without chemical fertilizers but only with the sources allowed by organic farming rules under Egyptian conditions. The extensive use of manufactured chemical fertilizers on the Nile valley soils has increased crops productivity but compromised quality especially for medicinal and aromatic plants which are not acceptable for export. Coupled to this, most of the new reclaimed land in Egypt are sandy soils which are normally poor in essential plant nutrients. In the rural areas, organic fertilization play an important role in agricultural productivity. Fennel an important medicinal plant grows well under Egyptian conditions and plays an important role in foreign exchange earnings. To investigate the effect of organic and inorganic sources of N, P and K on the fennel fruits yield and essential oil, it was important to study the effect of different treatments on soil fertility parameters, total content of macro- and micronutrients in the fennel herbs and fennel growth parameters at different physiological stages.

Field trials have been started to investigate the effect of different nitrogen sources on the yield of fennel fruits and essential oil. The natural sources of N (sources allowed by organic farming rules): compost, compost/*Azotobacter* and chicken manure in comparison with ammonium nitrate (chemical fertilizer). Phosphorous fertilization has been done with rock-P alone and rock-P mixed with elemental S (sources allowed by organic farming rules) and superphosphate as chemical fertilizer. Different potassium sources have been tested also, potassium given as natural source as feldspar (source allowed by organic farming rules) or as chemical fertilizer in the form of potassium sulphate.

Two field experiments have been done in an area of newly reclaimed land (Sekem farm) and in comparison on old cultivated land in the Nile valley (Giza farm) during two successive seasons (1998/1999) and (1999/2000).

The investigations yielded the following results:

1. Generally soil fertility parameters, soil pH, macro- and micronutrients in the soil were not significantly affected by the different sources of N, P and K except organic sources in some cases giving higher available K, P and micro-nutrients than chemical fertilizers.
2. The total contents of macro- and micronutrients were not affected by the different sources of N, P and K except in some cases organic fertilization giving higher potassium contents than chemical fertilization.

3. Generally fertilization with chemical fertilization of N, P and K (ammonium nitrate, calcium superphosphate and potassium sulphate) gave higher fennel growth parameters than did fertilization with the natural sources of N, P and K.
4. Compost/*Azotobacter*, rock-P/S and feldspar as the natural sources of N, P and K were more effective in increasing fennel growth and in many cases giving similar results as chemical fertilization.
5. Ammonium nitrate gave the highest fruit yields in both seasons and on both soils. Fertilization with compost on clay loam soil resulted in 17% and 7 % less of the yield obtained after fertilization with ammonium nitrate and 1 % and 12 % less on sandy soil in both growing seasons respectively.
6. Fertilization with chicken manure gave 92 % from the yield of the plots fertilized with ammonium nitrate in both growing seasons in the Nile valley (Giza farm) and 98 % and 85 % on Sekem farm in the first and second growing season respectively.
7. Fertilization with compost/*Azotobacter* increased the fruit yield by 14 % and 5 % compared with fertilization with compost alone on Giza farm (Nile valley). Results on sandy soil (Sekem farm) have been – 3 % and + 6 % respectively.
8. Yields of fennel oil showed the same trends as observed for the fruit yields.
9. Fertilization with super-phosphate gave the largest yield of fennel fruits and essential oil in the first season on both soils (Giza and Sekem). While in the second season fertilization with rock-P/S and rock-P alone gave the largest yields on Giza farm and Sekem farm respectively.
10. Generally essential oil content and the main components in the fennel fruit oil were not affected significantly by fertilization with organic and inorganic sources of N, P and K.

ZUSAMMENFASSUNG

Einfluss von Düngern des konventionellen und ökologischen Landbaus auf Ertrag und Ölqualität von Fenchel (*Foeniculum vulgare* Mill.) in Ägypten

In der vorliegenden Arbeit wurde untersucht, ob es mit den Vorgaben des ökologischen Landbaus zur Düngung möglich ist, ausreichende und qualitativ hochwertige Fenchel-Erträge in Ägypten zu produzieren. Fenchel ist eine wichtige Heilpflanze, die unter den klimatischen Bedingungen Ägyptens gut wächst und einen wichtigen Devisenbringer, insbesondere für kleinbäuerliche Landwirtschaft, darstellt.

Neulandflächen in Ägyptens sind meist Sandböden, die arm an essentiellen Pflanzennährstoffen sind und daher der Düngung bedürfen. Ziel der Arbeit war es, den Einfluß von im ökologischen Landbau zugelassen organischen und anorganischen N, P und K Dünger auf den Ertrag von Fenchel und den Gehalt an essentiellen Öle in Feldversuchen zu untersuchen.

Geprüft wurden Kompost, Kompost/*Azotobacter*, Geflügelmist, Rohphosphat, Rohphosphat in Mischung mit elementarem Schwefel und natürlicher Feldspat.

Als Kontrolle wurden Ammoniumnitrat, Superphosphat und Kaliumsulfat verwendet.

Die Feldversuche wurden zum einen in der Neuland-Region der Wüste (Sekem) sowie auf seit langen landwirtschaftlich genutztem Land im Nil Tal (Giza) während zweier Vegetationsperioden (1998/1999 und 1999/2000) durchgeführt.

Die Untersuchungen kamen zu folgenden Ergebnissen:

1. Generell wurden Parameter der Bodenfruchtbarkeit (pH, verfügbare Makro- und Mikronährstoffe) nicht signifikant von den verschiedenen Düngern beeinflußt. Jedoch war bei organischer Düngung in einigen Fällen eine höhere Pflanzenverfügbarkeit von Bodennährstoffen festgestellt.
2. Der Gesamtgehalt an Makro- und Mikronährstoffen in Fenchel waren bei konventioneller Düngung und bei Düngung nach Richtlinien des ökologischen Landbaus gleich hoch.
3. Der Einsatz konventioneller Dünger (Ammoniumnitrat, Superphosphat und Kaliumsulfat) führten tendenziell zu größerer Wuchshöhe, Triebzahl und höheren Trockengewichten.

4. Insgesamt waren aber die Ölerträge und die Ölzusammensetzung bei Düngung nach Regeln des ökologischen Landbaus nur unwesentlich von den konventionell gedüngten Pflanzen verschieden.

Als Schlußfolgerung kann daher, zumindest aus Sicht der Pflanzenernährung, die Produktion von Fenchel in Ägypten nach den Regeln des ökologischen Landbaus empfohlen werden, um die Ertragslage kleinbäuerlicher Landwirtschaft und damit die Lebensqualität im ländlichen Raum zu verbessern.

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8 ABBREVIATIONS

Amm.	Ammonium
ANOVA	Analysis of Variance
Avail.	Available
Azotob.	*Azotobacter*
C	Carbon
Ca	Calcium
CAL	Calcium ammonium lactate
CK	Control
cm	centimetre
Conc.	Concentrated
Cu	Copper
ds m^{-1}	decisiemens per meter = m mho cm^{-1}
DTPA	diethleyne triamin penta acetic acid
EC	Electrical conductivity
EU	European Union
FAO	Food and Agriculture Organization
Fe	Iron
Fig.	Figure
g	gram
GC	Gas Chromatography
GC-MS	Gas Chromatography-Mass Spectrometry
GLC	Gas Liquid Chromatography
GLM	General Linear Model
ha.	hectare
ICP-ASE	Inductively Coupled Plasma Emission Spectrometry
K	Potassium
l	litre
m eq.	m. equivalent
Mn	Manganese
N	Nitrogen
n. d.	Not detected
O. M.	Organic matter
P	Phosphorus
PC	Personal Computer
pH	Soil reaction
Potass.	Potassium
Rock-P	Rockphosphate
Rock-P/S	Rock phosphate + Elemental Sulphur
S	Elemental sulphur
Super-P	Superphosphate
Tab.	Table
WHO	World Health Organization
Zn	Zinc

9 LIST OF TABLES

9 LIST OF FIGURES

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